# THE EFFECTS OF TILLAGE, CROPPING AND FERTILIZATION ON EXTRACTABLE SOIL NUTRIENTS IN FOUR AGRO-ECOSYSTEMS IN GHANA, WEST AFRICA

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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August 2014

Major Subject: Soil Science

# ABSTRACT

Two experiments were conducted in four agro-ecosystems of Ghana: the coastal savannah, forest, forest-guinea savannah transition and guinea savannah. Experiment one assessed the effect of three tillage and four cropping treatments while experiment two quantified the effect of three triple super phosphate applications and six urea or compost applications. Two years after treatments commenced, soils were collected from a depth of 15 cm, air dried and sieved to 2 mm prior to acid extraction and analyses of Extractable Organic Carbon, Total Extractable N, $NH_4$-N-N, $NO_3$-N, $Ca^{2+}$, $Mg^{2+}$, $Na^{2+}$ and $K^+$.  Although no strong and significant predictive models could be created for experiment one, in experiment two a promising predictive model could be created for $K^+$ using agro-ecosystem and N application. Further findings indicate that agro-ecosystem had the largest effect on soil nutrient concentrations while the application of soil amendments will enhance extractable soil nutrients.

# DEDICATION

This thesis is dedicated to my family, friends and professors for all their patience and support. I can never thank you all enough.

# ACKNOWLEDGEMENTS

I would like to thank my committee co-chairs, Dr. Jacqueline A. Aitkenhead-Peterson and Dr. William A. Payne, and my committee member Dr. Frank M. Hons for all their patience, guidance and support throughout the course of this research. I would also like to thank the Howard G. Buffett Foundation and the Texas A&M Conflict & Development Center for funding this research, providing stipend support and allowing me the opportunity to twice travel to Ghana to collect samples and gain valuable field research experience. Another thank you goes to Dr. Kofi Boa and his team at the Center for No-Till Agriculture for all their assistance in collecting soil samples and being excellent hosts.

A big thank you goes to Nina Stanley for all her help with laboratory procedures and soil nutrient analysis. Another thank you goes to Lauren K. Pitts for continuing this research, travelling to Ghana and all our discussions. I would also like to thank the Soil and Crop Science Department faculty, staff and students for making my time at Texas A&M a great experience.

## NOMENCLATURE

| | |
|---|---|
| NT | No Tillage |
| ZT | Zonal or Minimum Tillage |
| TT | Traditional Tillage |
| CA | Conservation Agriculture |
| M | Maize |
| MC | Maize-Cowpea Rotation |
| MM | Maize-Mucuna Rotation |
| MCM | Maize-Cowpea-Mucuna Relay |
| CM | Cowpea Maize |
| MCI | Maize Cowpea Intercrop |
| SOM | Soil Organic Matter |
| SOC | Soil Organic Carbon |
| EOC | Extractable Organic Carbon |
| TEN | Total Extractable Nitrogen |
| EON | Extractable Organic Nitrogen |

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# 1. INTRODUCTION

## 1.1 Overview of African agriculture

The African continent covers an area of approximately 3.01 x $10^9$ hectares and has a wide range of soil orders and climatic conditions. In general, the climate in Africa can be characterized as arid, semi-arid or tropical. The majority of the soils found in Africa are considered highly weathered and low in fertility due to general overuse, erosion and leaching of nutrients (Breman et al., 2001; Drechsel et al., 2001). In addition, rapid population growth along with inappropriate land use, poor management and lack of nutrient inputs have led to a decline in productivity, increased soil erosion and salinization and the overall loss of vegetation (Bationo et al., 2006).

The major soil groups found in Africa are Aridisols (35%), Alfisols (22%), Oxisols (22%), Entisols (12%), Ultisols (4%), Vertisols (2%), and Mollisols and Inceptisols (3%) (Mrabet, 2002). According to Mrabet (2002) some of the constraints facing African soils are weathering, soil acidity, tendency for occluded phosphorus, the risk of multiple nutrient deficiencies and increased nutrient toxicities due to the increasing intensity of cultivation resulting in soils susceptibility to leaching nutrients along with a high risk of erosion and overall low fertility.

Traditional farming practices in Africa are characterized as slash and burn shifting cultivation where farmers clear the land and burn the vegetation before cultivating with a hand-held hoe. Often, farmers will farm the land for 1-3 years before moving to a new site, eventually returning 4-20 years later (Vaagen et al., 2005). Historically, this fallow period provided enough time for the soil to recover and there was enough land available to facilitate slash and burn agricultural practices. However, rapid population growth has resulted in a decrease in land, a reduction in fallow periods, as well as more intensive cultivation of marginal lands and the clearing of forests for agriculture (Subbarao et al., 2000; Vaagen et al., 2005). Overall, the this increased pressure on arable land has led to increased soil erosion, a decline in soil fertility and lower crop yields due to the loss of soil organic matter and essential nutrients.

## 1.2 Methods to increase soil fertility and organic carbon

### 1.2.1 Tillage

To combat the issues of low soil fertility and erosion, no-till (NT) practices, which leave crop residue on the soil surface, have been promoted as a cost-effective solution to improve crop yields, soil structure, nutrient concentrations, soil organic matter content (SOM), soil water-holding capacity and reduced erosion (Lal, 2006). Studies in Africa on the effect of NT practices have supported the adoption of this farming technique due to the beneficial effects on soil organic carbon (SOC) or SOM in the topsoil which, in turn, increases the soil water holding capacity and ultimately crop yield (Mrabet, 2002). According to Bayer et al. (2001), increasing the SOC pool of degraded soils can increase crop yields by increasing available water capacity, improving the supply of nutrients and enhancing soil structure. Furthermore, reversing the soil degradation and potential desertification through the enhancement and preservation of SOC will also enhance the cation exchange capacity (CEC) of the soil and improve soil microbial function resulting in improved supply of nutrients (Lal, 2006). Over the past few decades, the importance of organic matter has become a focal point in West African agricultural research, primarily due to organic matter being considered valuable to low-input farming systems in sub-Saharan Africa (Manlay et al., 2002).

Crop residue is used as fodder for livestock or fuel for cooking in many parts of Africa so it is difficult to mulch or keep the soils covered (Bationo et al., 1991). Realizing this constraint, Mchunu et al. (2011) investigated the impact of no-till on soil and SOC and erosion under crop residue scarcity in South Africa. This study evaluated the effect of runoff, soil, and SOC losses from traditional small-scale maize (*Zea mays*) fields under conventional tillage (CT) and NT, with crop residue cover of less than 10% during the rainy season (Mchunu et al., 2011). They found that NT significantly improved the SOC concentrations and pools in the 0 - to 2 cm layer by 33% and 26% respectively when compared to conventional tillage. They further concluded that a very limited amount of crop residue left on the soil surface need not be a limitation for SOC sequestration (Mchunu et al., 2011). The use of NT reduced soil losses by 68% and SOC losses by 52% in this South African study (Mchunu et al., 2011). This may be due to the creation of structural crusts formed under NT, which may reduce the opportunity of soil detachment during heavy rain or wind events (Mchunu et al., 2011). The scarcity of crop residue should not be considered a limiting factor to the adoption of NT as it was observed in the Mchunu et al., (2011) study to be a more sustainable farming practice compared to traditional tillage.

Recently, simulation models have been used to predict the long-term impacts of climate variability, soil tillage and water availability on smallholder production systems in Africa (Goutorbe et al., 1997; Chikowo et al., 2008; Andersson et al., 2009; Mupangwa et al., 2011). Of particular interest was the study by Mupangwa et al. (2011) who created a 95-year simulation model to assess the long-term impact of NT (without mulch) compared to CT on field water fluxes and maize productivity. Their predictions showed significantly higher surface runoff using CT compared to NT, higher deep drainage of water when using NT compared to CT regardless of the rainfall pattern, and that 62% of the annual rainfall was lost through soil evaporation from both tillage systems (Mupangwa et al., 2011). Although the difference between the predicted yields under each tillage system were within 50 kg $ha^{-1}$ for 74% of the years used in the simulation, only 9% of the years in the model predicted a higher grain yield in the NT system compared to the CT system (Mupangwa et al., 2011). From these results, it was suggested that the use of NT may have potential for reducing surface runoff from smallholder fields and may recharge groundwater resources through increased deep drainage. It has also been demonstrated that without a mulch or cover crop, small-scale farmers in semi-arid environments can experience high soil water evaporation and low crop yields (Mupangwa et al., 2011). It is important to note, however, that the model has major shortcomings and the findings need to be confirmed by further field-based and modeling studies (Mupangwa et. al., 2011). Another simulation study used the organic matter models CENTURY 4.0 and RothC-26 3 to explore the effects of modifying agricultural practices to increase soil carbon stocks (Farage et al., 2007). Using the dry lands of Nigeria, Sudan and Argentina, Farage et al. (2007) reported that the most effective practices were the ones that maximized the input of organic matter through the use of farmyard manure, agro-forestry and the adoption of NT.

In a long-term (25 year old) study of NT and CT in a sub-tropical dryland region of the USA, Gonzalez-Chavez et al. (2010) concluded that NT increased labile and more recalcitrant bio-products, along with an increase in SOC and total N compared to CT. These findings supported the work of Wright et al. (2005), who explored the impact of NT, CT and crop species on SOC and soil organic nitrogen (SON) sequestration and distribution within different aggregate-size fractions in the same fields used in the Gonzalez-Chavez et al., (2010) study. Wright et al. (2005) indicated that NT had the potential to increase soil C and N in surface soils and further suggested that NT combined with crop rotation should be recommended for increased soil C sequestration. Overall, there appeared to be benefits to soil health with the adoption of NT in these dryland soils of Texas.

Reduced tillage is only likely to have a strong positive effect on SOM in finer-textured clayey or silty soils (Chivenge et al., 2007). This is due to the lack of physical and structural protection sandy soils offer SOM. As a result, organic matter content in sandy soils will depend on regular additions of crop residues.

### 1.2.2 Cropping systems and soil amendments

A wide diversity of staple crops such as maize, cowpea (*Vigna unguiculata*), sorghum (*sorghum L.)*, millet (*Pennisetum glaucum*), banana (*Musa × paradisiaca*), wheat (*Triticum),* rice (*Oryza glaberrima*) and cassava (*Manihot esculenta*), are found across Africa. Fasinmirin et al. (2011) examined the effects of different tillage and mulch treatments on crop yield and soil physical properties such as compaction, bulk density and soil porosity on cassava production. Mulching has been shown to be a beneficial practice across Africa. For example, crop residue studies have shown that leaving the crop residue on the field may result in lower soil bulk density at the soil surface (0 – 5 cm) (Lal, 1987; Mando et al., 1999; Bationo et al., 2007; Giller et al., 2009). Mulch can improve the soil structure of the surface soil along with improving soil water conservation, reducing soil temperature due to residue cover and can improve the above ground biomass of cassava compared to CT (Fasinmirin et al., 2011). Cassava is one of the main staple food crops in the tropical and sub-tropical regions of the world, with Africa accounting for around 42% of world production (Fasinmirin et al., 2011). It is important to remember that cassava is a root crop and Fasinmirin et al. (2011) concluded that root penetration resistance was higher under NT than in CT and zonal or minimal tillage [ZT]. While root penetration resistant could have a negative effect on cassava root yield, the nutrient build up under NT resulted in optimum crop yields (Fasinmirin et al., 2011). Cassava root yields tended to be slightly better under NT with fertilization and mulch compared to CT under the same fertilizer and mulch treatment (Fasinmirin et al., 2011). Without mulch, cassava root yield under fertilizer treatments alone reduced from 6.11 t $ha^{-1}$ with mulch to 4.42 t $ha^{-1}$ without mulch for NT compared to 5.92 t $ha^{-1}$ with mulch to 5.51 t $ha^{-1}$ without mulch for CT (Fasinmirin et al., 2011). These results clearly show the importance of mulch for NT cassava production in providing SOM and soil protection. The findings of Fasinmirin et al. (2011) also supports the work of Lal (1986), who examined the effects of NT and puddling systems (the tillage of rice paddies while flooded) for rice production in Nigeria. Using four treatments of N application (0, 50, 100 and 150 kg $ha^{-1}$) and growing eleven consecutive crops of rice, resulted in an average grain yield of 3.5 t $ha^{-1}$ and 5.5 t $ha^{-1}$ per crop under NT fertilized at 0 and 150 N kg $ha^{-1}$ respectively. The puddling system produced 3.9 t $ha^{-1}$ and 5.6 t $ha^{-1}$ of rice under the same N applications indicating that the puddling system produced a slightly greater yield at low N application compared to NT. Lal (1986) also reported that the retention of crop residue (mulch) led to an average organic C content of 2.2 % (w/w) in the 0 - 5 cm layer of NT treatments compared to 1.7% (w/w) in the puddling treatment after 6 years of treatments. Overall the major findings of Lal (1986) were that the surface layer of NT treatments had higher SOM, higher total N content, lower soil bulk density, as well as higher water retention than puddled soil. The results of Lal (1986) concur with other studies of cropping systems in Africa under NT, particularly the production of higher SOM, N content and water retention (Mrabet, 2002; Obalum et al., 2011). The main conclusion was that the NT system of producing transplanted, irrigated lowland rice was agronomically feasible for intensive use of tropical wetlands as long as the soil is of medium texture and had poor structural properties (Lal, 1986).

### 1.2.3 Combined tillage and cropping systems

There is growing evidence in Africa for the need of cover crops to improve SOM fractions and increase C and N pools (Snapp et al., 1998). One such study by Bayer et al. (2001) assessed the 12-year changes in SOM fractions under sub-tropical NT cropping systems by comparing C and N pools in particulate and mineral associated soil pools in three NT systems (1) Bare Soil, (2) Oat + Vetch and Maize + Cowpea rotation, and (3) Maize + Cajanus. They reported that cropping systems that included cover crops in NT systems increased C and N pools in both particulate and mineral associated SOM when compared to bare soil. Furthermore, their results indicated that mineral-associated SOM had 5 - 9 times more C and 13 - 26 times more N than particulate organic matter (Bayer et al., 2001). Somewhat similar results were found in a 25 year long study in dryland areas of Texas assessing different tillage and cropping systems. Here, their results determined that the adoption of NT with a crop rotation resulted in a richer and more diverse soil microbial community as well as an increase in labile and recalcitrant C compared to CT with a crop rotation (Gonzalez-Chavez et al., 2010). In the humid forest zone of southern Cameroon an assessment NT and alley cropping, found that NT increased SOC and total N after two years compared to hand tillage (Hulugalle et al., 1993). While alley cropping caused a reduction in surface seal formation and cassava root growth an increase in exchangeable Ca, effective CEC and water infiltration was observed (Hulugalle et al., 1993).

## 1.3 Limitations to conservation agriculture

Although there are benefits to adopting conservation agriculture (CA), Giller et al. (2009) noted that there are a number of limitations to CA and questioned its suitability in sub-Saharan Africa. In particular, Giller et al. (2009) focused on the need to consider the biophysical, socio-economic and cultural constraints that might hinder the adoption of CA. Some of the constraints farmers might face are: (1) a low degree of mechanization within the smallholder system, (2) a lack of appropriate implements, (3) a lack of technical information, (4) blanket recommendations that ignore the resource status of rural households, (5) competition for crop residues in mixed crop-livestock systems, (6) limited availability of household labor and (7) the need for an immediate return on investment (Giller et al., 2009). Variability in the results of studies on CA also demonstrate that the potential of benefits of CA are site-specific and depend on the local bio-physical and socio-economic environments (Giller et al., 2009).

## 1.4 Soil fertility and fertilization

There is a large variability of soil fertility within fields on smallholder farms in Sub – Saharan Africa (Mtambanengwe et al., 2005; Rowe et al., 2006). This is because smallholder farms comprise multiple plots that are managed differently in terms of crops grown, fertilizers applied and labor resources available (Mtambanengwe et al., 2005). These management factors and other influencing within-field and farm soil fertility gradients and SOC were identified among sites with more than 70 years of cultivation in Zimbabwe. Mtambanengwe et al. (2005) concluded that the management of soil fertility gradients to increase crop productivity on smallholder farms depended on increasing the capacity and efficiency to generate and utilize SOM. Findings also showed that SOM, available P and CEC decreased with distance from the homestead on most farms (Mtambanengwe et al., 2005). Furthermore, nutrient balances on the farms studied seemed to be strongly driven by access to manure (cattle ownership) and the use of mineral fertilizers (Mtambanengwe et al., 2005).

### 1.4.1 Organic fertilizer

Historically, farmers in the semi-arid regions of Africa have utilized organic manure on their fields to increase nutrients and SOM content (Snapp et al., 1998). A study conducted east of Nairobi, Kenya, examined the sources of nutrients applied to counteract soil fertility depletion (Omiti et al., 1999). A reported 86% of farmers in the study used animal manure, 13% used inorganic fertilizer, 13% used compost, 3% used green manure and 7% of farmers used nothing; some farmers used more than one type of soil amendment (Omiti et al. 1999). Much of the research has been undertaken on the effects of different fertilization practices on soil C, N and P across Africa. In the 1990’s, Agbenin et al. (1997) assessed soil C, N and P dynamics after 45 years of continuous cultivation and how the soils (all Alfisols) were influenced by farmyard manure and inorganic fertilizers in the savanna region of northern Nigeria. The study used a mixed cropping system, with a 10 year of a rotation of cotton (*Gossypium hirsutum*), guinea corn and groundnut (*Arachis hypogaea*) (1950-1960), followed by continuous cotton (1961-1970) and then from 1976-1995 groundnut rotated with maize they reported that applying farmyard manure alone or in combination with N + P or N + P + K fertilization, was most effective in maintaining soil fertility. Inversely, continuous inorganic fertilization reduced soil fertility due to the depletion of organic matter, a key source of plant available N and P in weathered, tropical soils (Agbenin et al., 1997).

### 1.4.2 Inorganic fertilizer

Inorganic fertilizer has been said to have the potential to raise the productivity of smallholder farms, which will help increase income, accumulate assets and serve as a pathway out of poverty (Benson et al., 2012). Its use in sub-Saharan Africa has been limited compared to the rest of the world due to limited access and high costs of the product and yield variability due to drought (Yanggen et al., 1998). On the contrary, chemical or inorganic fertilizers have been widely adopted in rain-fed and irrigated agricultural systems (Ryan et al., 2012).

In 1970, sub-Saharan Africa on average used less than 5 kg $ha^{-1}$ of mineral fertilizers when other developing countries used more than 15 kg $ha^{-1}$. Since then, African fertilizer consumption has grown at only 0.23 kg $ha^{-1}$ $yr^{-1}$ and as of 1998, was at 9 kg $ha^{-1}$ $yr^{-1}$ compared to Latin America and Asia who used >50 kg and >80 kg $ha^{-1}$ $yr^{-1}$ of mineral fertilizer respectively (Yanggen et al., 1998). As recently as 2002, an average of 9 kg $ha^{-1}$ $yr^{-1}$ of mineral fertilizer was still referenced as use in Africa; nevertheless, there have been observations that parts of the continent are increasing mineral fertilizer use as better access and incentives are provided to farmers (Ariga et al., 2006). The capacity and efficiency to improve and maintain SOM while using inorganic fertilizers was assessed by Dube et al. (2012) who evaluated the effect of four fertilization regimes on SOM in an irrigated conservation agriculture system after four years of summer maize and winter oat as well as summer maize and winter grazing vetch rotations in the Eastern Cape, South Africa. Dube et al. (2012) suggested that in a low fertilizer input conservation agriculture system, fertilizer should be applied to the winter cover crops in order to receive a similar SOM response while also investing less fertilizer.

## 1.5 Objectives of study

The major objectives of this research will be to:

1. Determine the effect of different tillage and cropping techniques, and their interactions on farmer fields across four agro-ecosystems in Ghana on soil total extractable N (TEN), extractable organic N (EON) and extractable organic C (EOC), and on extractable soil $NO_3$-N, $NH_4$-N, $PO_4$-P, $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$.
2. Quantify the effect of different fertilizer sources and interactions of N fertilizer treatments and P fertilizer treatments on farmer fields across four agro-ecosystems in Ghana on soil total extractable N (TEN), extractable organic N (EON) and extractable organic C (EOC), and on extractable soil $NO_3$-N, $NH_4$-N, $PO_4$-P, $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$.
3. Examine the potential of multiple regression analysis for predictive models for soil nutrient status using tillage and cropping treatments and fertilizer treatments.

## 1.6 Hypotheses

H1: Reducing tillage will enhance EOC, TEN, $PO_4$-P and other nutrients.

H2: Use of a diversity of crop, along with rotations and intercropping, will enhance EOC, TEN, $PO_4$-P and other nutrients relative to soils under a monoculture.

H3: Application of inorganic fertilizer will increase extractable soil nutrient concentrations compared to organic fertilizer but will reduce EOC concentrations.

H4: Environmental metrics coupled with cropping and tillage treatments will enable soil nutrient status to be predicted across agro-ecosystems in Ghana

# 2. EFFECT OF TILLAGE AND CROPPING ON EXTRACTABLE SOIL NUTRIENTS

## 2.1 Introduction

Conservation agriculture (CA) is considered a sustainable solution to combat soil degradation and help increase soil fertility (Hobbs, 2007). Promoted as a holistic system, incorporating no-tillage (NT), crop residue management and crop rotations, the adoption of CA helped Brazilian farmers carry out the “zero-tillage revolution” (Hobbs, 2007). In Africa, CA has been promoted as a solution to improve soil productivity and address the interlinked issues of poverty, environmental degradation and low agricultural productivity (Bationo et al., 1998). Furthermore, the adoption of recommended management practices on agricultural lands and degraded soils could enhance soil quality including increasing the available water holding capacity, cation exchange capacity, soil aggregation, and reducing susceptibility to crusting and erosion (Lal, 2006). As more research is carried out in West Africa to assess the effects of CA practices on soil nutrient concentrations, farmers and government policy makers will be better informed to choose whether or not to follow the Brazilian model and adopt CA.

Over the past two decades, there has been growing evidence on the importance of soil organic carbon (SOC) in a multitude of African farming systems (Lal, 2006). In general, research across Africa has demonstrated that adopting NT increases soil organic matter (SOM) content in surface soil horizons and can result in higher concentrations of soil nutrients compared to plowed plots (Lal, 1976). When assessing the effects of CA on soils across the world, results have been inconclusive in determining whether SOC increases under CA (Ouedraogo et al., 2006; Giller at al., 2009; Govaerts et al., 2009). Assessment of soils in Africa are also inconclusive as to whether the adoption of NT can increase crop yields; nevertheless, some studies have shown that the adoption of NT increased soil water infiltration rates and soil moisture while reducing soil runoff and erosion (Lal, 1976; Theirfelder et al., 2009) which should in fact increase crop yields particularly in water stressed environments.

In West Africa, research has primarily focused on the individual effects of different components of CA such as tillage practices, crop rotations and fertilizer applications on soil moisture, SOC and crop yields (Bagayoko et al., 2000; Graham et al., 2002; Mrabet, 2002). Acknowledging that CA shows potential, is site specific and depends on local biophysical and socio-economic environments; research that takes into account reasons why CA may or may not be adopted has been lacking (Giller et al., 2009).

Conservation agriculture in semi-arid West Africa is currently being promoted to mitigate the effect of droughts, increase crop productivity and reduce production costs (Lahmar et al., 2012). The CA approach relies on the simultaneous use of minimal or zonal tillage (ZT) or no-tillage (NT), maintenance of a permanent soil cover and a diversified, profitable crop rotation (Lahmar et al., 2012) Research has shown that SOM, nutrients, pH, and texture are indicators of good soil quality (Reeves, 1997). Soil organic carbon (SOC) is used as a measure of SOM because soil humus, or SOM, is usually about 58% C by weight and therefore SOM can be calculated from SOC (*Dr. Frank M. Hons, personal communication*). Furthermore, SOC's chemical structure and surface properties influence soil structural stability and cation exchange capacity while also serving as an energy source for soil biota (Logah et al., 2011).

The objective of this research was to evaluate the effects of tillage and cropping and their interactions on extractable soil organic carbon (EOC), nitrogen species ($NO_3$-N, $NH_4$-N and extractable organic N [EON]), $PO_4$-P and cations ($Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$) concentrations in four agro-ecological zones in Ghana, West Africa. Based on prior research in West Africa it was hypothesized that NT or ZT and crop rotations or cover crops would result in significantly higher extractable soil nutrients compared to CT and single continuous cropping.

## 2.2 Materials and methods

### 2.2.1 Site description

Tillage and cropping treatments were established prior to the growing season in four agro-ecosystems in Ghana, West Africa in 2011. The agro-ecosystems were 1) coastal savannah, 2) forest, 3) forest-Guinea savannah transition and 4) Guinea savannah. The coastal savannah agro-ecosystem used in this study was situated in the Ga West district and Pokuase community. The soil was classified using the World Reference Base for soil resources (WRB**,** 2006) as a Haplic Lixisol formed on granite with a loamy-sand texture to 60 cm. The forest agro-ecosystem was in the Amansie West district within the Ahwerewa community. The soil was classified as a Leptic Lixisol formed on phyllite with a silty-loam texture to 60 cm. The forest-Guinea savannah transition agro-ecosystem was situated in the Ejura-Sekodumase district within the Ejura-Adiembra community. The soil was classified as Leptic Lixisol formed on sandstone with a loamy sand texture to 30 cm. The Guinea savannah agro-ecosystem was in the Tolon-Kumbungu district within the Kumbungu-Kuko community. The soil was classified as a Pisolithic Plinthosol formed on shalestone with a silty loam texture to 60 cm (Davies et al. 2014).

Historically, mean annual rainfall differs between the four agro-ecosystems. In the coastal savannah, mean annual rainfall is 810 mm however in 2012, it received 763 mm. In the forest agro-ecosystem, mean annual rainfall is 1500 mm but it only received 980 mm in 2012. Mean annual rainfall in the forest-Guinea savannah transition agro-ecosystem is 1300 mm however in 2012 it received 1092 mm of rain. Lastly, the Guinea savannah has a mean annual rainfall of 1100 mm but received 900 mm of rain in 2012 (*Dr. Kofi Boa, personal communication*). Apart from the differences in the mean annual rainfall, the distribution of precipitation across the four agro-ecosystems also differs. Each year there is a major (March-July) and minor (August- November) cropping season in the coastal savannah, forest and forest-Guinea savanna agro-ecosystem which is driven by the bimodal distribution of precipitation. In the Guinea savannah only has one annual cropping season occurs (August-November) due to the majority of precipitation falling between August and November (Figure 1).

### 2.2.2 Experimental design

In each of the agro-ecosystems studied, a split plot design was implemented to test the effects of cropping, tillage and cropping x tillage interactions. The main plots were either (1) no till (NT), (2) zonal or minimal tillage (ZT) or (3) traditional tillage (TT). In the coastal savannah, forest, and forest-Guinea savannah transition the sub-plots were either 1) maize (*Zea mays*) only, 2) maize – cowpea (*Vigna unguiculata*) rotation, 3) maize – mucuna (*Mucuna pruriens*) rotation, or 4) maize – cowpea – mucuna relay. In the Guinea savannah agro-ecosystem the sub-plots were either 1) maize (*Zea mays*) only, 2) maize – cowpea (*Vigna unguiculata*) rotation, 3) maize – cowpea intercrop or 4) cowpea – maize rotation.

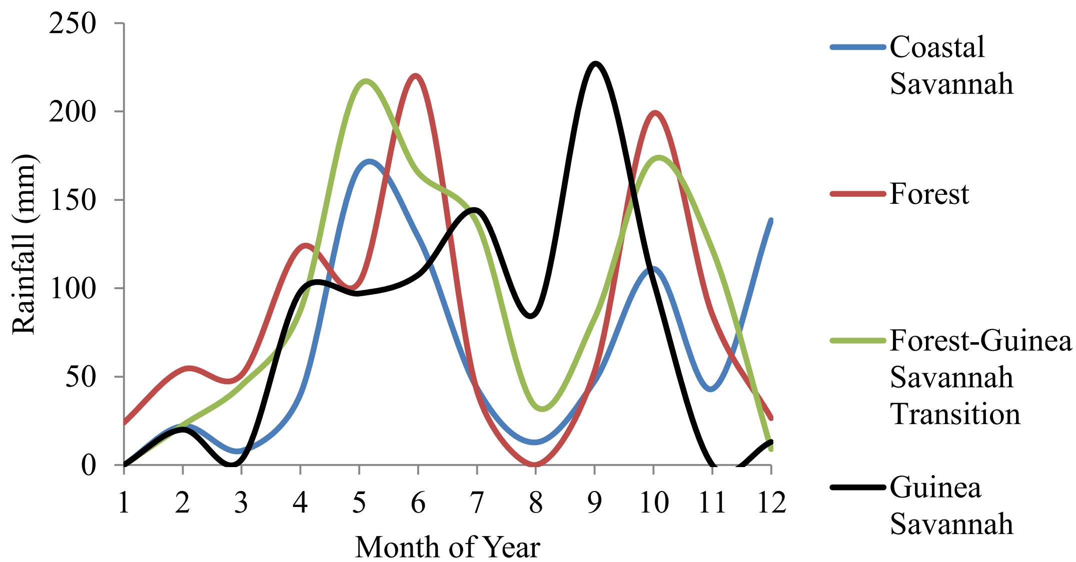


Figure 1. Distribution of rainfall in 2012 in the agro-ecosystems studied in Ghana. Source of data: Dr. Kofi Boa.

The reason for the difference in cropping is that the Guinea savannah has only one growing season each year compared to the other agro-ecosystems, which have two cropping seasons. The cropping seasons are based on the rainfall distribution in each agro-ecosystem (Figure 1).

Each individual plot was 5 m x 5 m with a crop row spacing of 80 x 40 cm with 2 seeds per hill for maize while cowpea was planted with a crop row spacing of 60 x 20 cm with 2 seeds per hill. Traditional tillage was determined as a hand held hoe in all zones except for the forest zone where slash and burn was primarily used. Three replicate plots for each treatment combination were available for soil sampling at each of the agro-ecosystems.

### 2.2.3 Soil sampling and processing

Soils were sampled in December 2012, two years after treatments were initiated using a 2 cm diameter soil probe to a depth of 15 cm. Due to the dependence on human labor and the use of hand-held hoes as the main tillage tool, soils in Ghana tends not to be tilled deeper than approximately 15cm. Since each plot was 5 x 5 m with 5-6 rows of planted crops, three soil cores were taken across the central row and bulked on site. Soils were air-dried and shipped to Texas A&M University for analysis.

Larger soil peds were gently broken using a mortar and pestle prior to sieving to <2 mm. Soil samples (3.5 g) were dissolved in 35 g of 0.1 M HCl (1:10 soil:HCl ratio) and shaken for two hours at 500 rpm on a rotary shaker. Samples were then centrifuged for 15 minutes at 19,974 g-force and filtered using a Whatman GF/F filter (nominal pore size 0.7 µm) (Davies et al., 2014).

Soil extracts were analyzed immediately after extraction for extractable organic C (EOC), total extractable N (TEN), $NH_4$-N-N, $NO_3$-N, $Ca^{2+}$, $Mg^{2+}$, $Na^{2+}$ and $K^+$. Extractable organic nitrogen (EON) was calculated by deducting $NO_3$-N plus $NH_4$-N from TEN.

To measure extractable P, the Bray 1 method was used (Bray et al., 1945). Soil samples (3 g) were dissolved in 21 g Bray 1 solution (1:7 Soil:Bray 1 ratio) and shaken vigorously by hand for 1 minute. Samples were then centrifuged for 5 minutes at 2,809 g-force and filtered with Whatman GF/F filters (nominal pore size 0.7 µm). Soil extracts were analyzed immediately after extraction for $PO_4$-P.

### 2.2.4 Chemical analyses

Extractable organic carbon (EOC) and total extractable nitrogen (TEN) were measured using a high temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH and Shimadzu total measuring unit TNM-1 (Shimadzu Corp. Houston, TX, USA). Extractable organic carbon (EOC) was measured as non-purgeable carbon, which entails acidifying the sample (250 µL 2 M HCl) and sparging for 4 min with C-free air. $NH_4$-N was analyzed using the phenate hypochlorite method with Na nitroprusside enhancement (USEPA method 350.1) and $NO_3$-N was analyzed using Cd-Cu reduction (USEPA method 353.3). $PO_4$-P was analyzed using the ascorbic acid, molybdate blue method (APHA 1992). All colorimetric methods were performed with a Westco Scientific Smartchem Discrete Analyzer (Westco Scientific Instruments Inc. Brookfield, CT, USA). $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$ were quantified by ion chromatography using an

Ionpac CS12A analytical and Ionpac CG12A guard column for separation and 20mM methanosulfonic acid as eluent at a flowrate of 1 mL $min^{-1}$ and injection volume of 25 μL (DIONEX ICS 1000, DIONEX Corp. Sunnyvale, CA, USA). Sample replicates, blanks, NIST (National Institute of Standards and Technology) traceable and check standards were run every 12th sample to monitor instrument precision and co-efficient of variance among replicate samples.

### 2.2.5 Statistical analyses

Prior to analyses, data was checked for normal distribution and outliers were removed if non-normal distribution was evident. Univariate analysis of variance with agro-ecosystem, tillage and cropping as fixed factors was performed to examine the effect of tillage, cropping and agro-ecosystem as well as interactions of agro-ecosystem x tillage, agro-ecosystem x cropping, tillage x cropping and agro-ecosystem x tillage x cropping on extractable soil nutrients. Univariate analysis of variance was also performed for each individual agro-ecosystem using tillage and cropping as fixed factors to examine their individual and interaction effects on soil nutrients. Two-sample, 1-tailed t-tests ($\alpha < 0.01$) were used to examine significant differences resulting from tillage and cropping within each agro-ecosystem. Significant effects (univariate analysis of variance) were determined when $p < 0.10$ while significant differences (2 sample, 1-tail t-tests) were determined when $p < 0.05$.

To determine if predictive models could be constructed to explain the percent variance in extractable soil nutrients a backward, stepwise, multiple regression analysis was performed for a) the whole dataset and b) individual agro-ecosystems. Pearson bivariate correlation analysis was performed on the whole dataset (the four agro-ecosystems) and on individual agro-ecosystem extractable nutrients to examine correlations among nutrients (1) across Ghanaian smallholder farms and (2) within each agro-ecosystem.

## 2.3 Results

### 2.3.1 Baseline soil nutrient status

Dr. Kofi Boa collected composite soil samples prior to planting and initiation of the tillage and cropping treatments (Davies et al., 2014). Analyses of these soils indicated that the soils in the coastal savannah and forest agro-ecosystems were moderately to slightly acidic across three depths (0-10, 10-30 and 30-50 cm), with pH ranging from 5.9 – 6.3 in the coastal savannah and 5.6 – 6.5 in the forest agro-ecosystems. Soils in the forest-Guinea savannah transition site were very acidic (pH 4.3 - 5.0), and those in the Guinea savanna site were acidic (pH 5.1 – 5.6) (Davies et al., 2014).

Baseline soil C:N ratios ranged from 10.0 to 5.0 in the coastal savannah indicating a larger soil pool of N at 30-60 cm depth compared to 0-10 cm depth. In the forest soil, C:N ratio ranged from 12.0 to 10.0 illustrating a steady C:N ratio with depth. The transition zone had a soil C:N ratio of 11.7 to 14.0 and the guinea savannah a C:N ratio of 16.7 to 20.0 (Davies et al., 2014).

### 2.3.2 Univariate analysis of variance across the four agro-ecosystems in Ghana

A univariate analysis of variance was performed with tillage and cropping treatments and agro-ecosystem type as fixed factors (N = 144) to assess the effects and interactions on extractable soil nutrients (Table 1). Agro-ecosystem had a significant effect on all extractable nutrients with the exception of the EOC:EON ratio and EOC:TEN ratio. Tillage had no significant effect on any of the extractable nutrients; there was however an interaction effect of tillage x agro-ecosystem on EOC ($p = 0.08$) and $Ca^{2+}$ ($p = 0.06$). Cropping did not have a significant effect on any of the extractable soil nutrients either across the four agro-ecosystems studied but there was a significant interaction effect of cropping x agro- ecosystem on $PO_4$-P ($p = 0.047$), EOC:$PO_4$-P ratio ($p = 0.02$) and the TEN:$PO_4$-P ratio ($p = 0.087$). There were no significant interaction effects of tillage x cropping or of tillage x cropping x agro-ecosystem.

Table 1. Univariate analysis of variance for the four agro-ecosystems in Ghana. EOC=Extractable Organic C, EON=Extractable Organic N. *Significant at $p < 0.10$ and **Significant at $p < 0.05$. n = 144

| | | Tillage | Cropping | Zone | Tillage x Cropping | Tillage x Zone | Cropping x Zone | Tillage x Cropping x Zone | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| $NO_3$-N | F | 0.42 | 0.88 | 48.12 | 0.39 | 0.79 | 0.57 | 0.83 | 0.65 |
| | *p* | *0.66* | *0.45* | ***0.00*** | *0.82* | *0.88* | *0.58* | *0.66* | |
| $NH_4$-N | F | 1.13 | 0.32 | 15.81 | 0.72 | 0.72 | 0.37 | 0.52 | 0.43 |
| | *p* | *0.33* | *0.81* | ***0.00*** | *0.64* | *0.63* | *0.95* | *0.94* | |
| $PO_4$-P | F | 0.91 | 2.85 | 21.55 | 1.04 | 1.32 | 2.69 | 1.08 | 0.58 |
| | *p* | *0.40* | ***0.04*** | ***0.00*** | *0.40* | *0.25* | ***0.01*** | *0.38* | |
| EOC | F | 1.96 | 0.58 | 66.95 | 0.50 | 2.10 | 0.58 | 0.91 | 0.72 |
| | *p* | *0.15* | *0.63* | ***0.00*** | *0.81* | ***0.06**** | *0.81* | *0.57* | |
| EON | F | 0.23 | 0.63 | 26.54 | 1.02 | 0.29 | 0.70 | 1.18 | 0.55 |
| | *p* | *0.80* | *0.60* | ***0.00*** | *0.42* | *0.94* | *0.71* | *0.29* | |
| $Na^+$ | F | 2.25 | 1.84 | 18.05 | 0.95 | 0.90 | 0.73 | 0.67 | 0.49 |
| | *p* | *0.11* | *0.14* | ***0.00*** | *0.46* | *0.50* | *0.68* | *0.83* | |
| $K^+$ | F | 0.85 | 0.76 | 22.02 | 0.12 | 0.62 | 1.54 | 0.86 | 0.52 |
| | *p* | *0.43* | *0.52* | ***0.00*** | *0.99* | *0.71* | *0.14* | *0.63* | |
| $Mg^{2+}$ | F | 2.93 | 1.08 | 557.51 | 0.54 | 1.78 | 1.06 | 1.09 | 0.95 |
| | *p* | ***0.06**** | *0.36* | ***0.00*** | *0.78* | *0.11* | *0.40* | *0.37* | |
| $Ca^{2+}$ | F | 0.35 | 0.17 | 127.05 | 0.46 | 0.93 | 0.53 | 0.37 | 0.81 |
| | *p* | *0.70* | *0.91* | ***0.00*** | *0.83* | *0.48* | *0.85* | *0.99* | |

2.3.3 Effect of tillage and cropping on soil nutrients in the coastal savannah

Three tillage treatments: NT, ZT and TT and four cropping treatments: sole maize (M), maize-cowpea rotation (MC), maize-mucuna rotation (MM) and maize-cowpea-mucuna relay (MCM) were used in the coastal savannah. Univariate analysis of variance with tillage and cropping as fixed factors determined that tillage had a significant effect on extractable $Mg^{2+}$ ($p = 0.09$) but no significant effect on any other extractable nutrients. Cropping had a significant effect on; $PO_4$-P ($p = 0.04$) and $K^+$ ($p = 0.04$) but there was no significant interaction of tillage and cropping on any soil nutrients in the coastal savannah agro-ecosystem (Table 2).

Table 2. Results of univariate analysis of variance in the Coastal savannah agro-ecosystem. *Significant at $p < 0.10$ and **Significant at $< 0.05$. n = 36

| | $PO_4$-P | | $K^+$ | | $Mg^{2+}$ | |
|---|---|---|---|---|---|---|
| Treatment | F Value | p value | F Value | p value | F Value | p value |
| Tillage | 1.44 | 0.26 | 1.15 | 0.33 | 2.73 | 0.086* |
| Cropping | 3.1 | 0.045** | 3.33 | 0.037* | 0.37 | 0.78 |
| Tillage x Cropping | 1.19 | 0.34 | 1.38 | 0.26 | 0.56 | 0.76 |

Within the coastal savannah region, $NO_3$-N concentrations ranged from 9.9±2.8 to 19.8±16.1 mg $kg^{-1}$, $NH_4$-N concentrations ranged from 5.6±0.7 to 7.2±2.5 mg $kg^{-1}$ and EON concentrations ranged from 5.0±2.8 to 12.0±3.7 mg $kg^{-1}$. Most of the N was in the in-organic form. $PO_4$-P concentrations ranged from 5.7±2.2 to 25.2±22.7 mg $kg^{-1}$ and EOC concentrations ranged from 48.9±6.4 to 74.9±14.6 mg $kg^{-1}$. Cation concentrations ranged from 16.2±5.5 to 43.4±32.5 mg $Na^{+}$ $kg^{-1}$, from 22.5±2.7 to 47.0±8.8 mg $K^{+}$ $kg^{-1}$, from 58.7±6.6 to 86.6±15.0 mg $Mg^{2+}$ $kg^{-1}$ and from 296.4±34.8 to 415.5±132.9 mg $Ca^{2+}$ $kg^{-1}$ (Table 3).

#### 2.3.3.1 Tillage

There was no significant difference between NT or ZT on extractable soil $NO_3$-N, $NH_4$-N or EON but plots planted with MM and MCM under TT had significantly higher $NH_4$-N concentrations when compared with the same crops under ZT (Table 3). Neither NT nor ZT had a significant effect on extractable soil $PO_4$-P (Table 3). Under M, TT had significantly higher concentrations of EOC (74.9±14.6 mg $kg^{-1}$) compared to the same crop under ZT (52.7±3.6 mg $kg^{-1}$).

Extractable soil $Na^{+}$ was significantly affected by NT where significantly higher concentrations were observed under MM when compared with the same crop with TT and ZT (Table 3). Under other cropping treatments, there was no effect of ZT or TT on extractable $Na^{+}$. NT also had significantly higher concentrations extractable $K^{+}$ under M and MM compared to the same crops with TT and ZT (Table 3). There was no effect of tillage on extractable $Mg^{2+}$ or $Ca^{2+}$ in the TT plots across cropping systems but there were significantly higher $Ca^{2+}$ concentrations under MC in the NT treatments compared to the TT treatments (Table 3).

#### 2.3.3.2 Cropping

There was no significant difference between cropping systems for extractable $NO_3$-N or $NH_4$-N (Table 3). EON concentrations were significantly higher under MCM cropping compared to MC cropping under ZT.

Extractable $PO_4$-P concentrations were significantly affected under M cropping compared to MC and MM with TT (Table 3). For other cropping treatments, MC, MM and MCM, there was no effect of cropping on soil $PO_4$-P concentrations irrespective of tillage (Table 3). Neither MC nor MM cropping had a significant effect on extractable soil EOC irrespective of tillage treatments. EOC concentrations were significantly increased under M compared to MC and MM under TT. Under ZT the MCM crops had significantly higher EOC concentrations compared to M and MC (Table 3).

Extractable soil $Na^+$ concentrations were not significantly different under M or MC irrespective of tillage. $Na^+$ concentrations were significantly higher under MM (27.9±4.0 mg $kg^{-1}$) and MCM (25.5±9.4 mg $kg^{-1}$) compared to MC (18.9±2.3 mg $kg^{-1}$) under the NT treatments. Extractable $K^+$ concentrations were significantly higher under M compared to MM under both TT and ZT (Table 3). Significantly lower concentrations of $K^+$ were also observed under MCM crops (24.9±5.3 mg $kg^{-1}$) when compared to M (47.0±8.8 mg $kg^{-1}$), MC (42.0±8.5 mg $kg^{-1}$) and MM (39.9±2.0 mg $kg^{-1}$) under NT.

Significantly higher concentrations of extractable soil $Mg^{2+}$ was observed under M and MC cropping compared to MCM cropping in NT treatments (Table 3). There was no significant effect of MM or MCM cropping on extractable $Mg^{2+}$ irrespective of tillage.

Table 3. Soil nutrients in the Coastal Savannah agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (ab) within each tillage groups shows significant effect of cropping at $p<0.05$. Differences in superscript letters (xyz) within cropping groups shows a significant effect of tillage at $p<0.05$. Tillage: None = No Till, Trad = Traditional Tillage and Zonal = Zonal Tillage. Cropping: M = Sole Maize, MC =Maize-Cowpea rotation, MM = Maize-Mucuna rotation and MCM = Maize-Cowpea-Mucuna relay[1]

| Till | Crop | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg $kg^{-1}$ | | | | | | | | | |
| None | M | 19.8±16.1 | 7.2±2.5 | 25.2±22.7 | 56.0±7.9 | 31.6±10.6 | 6.2±5.4 | $^{a}$19.5±5.6 | $^{yb}$47.0±8.8 | $^{b}$81.7±8.0 | 382.6±38.7 |
| None | MC | 10.9±0.6 | 5.8±0.9 | 6.0±3.0 | 58.8±8.8 | 22.2±8.0 | 6.3±5.6 | $^{a}$18.9±2.3 | $^{b}$42.0±8.5 | $^{b}$86.6±15.0 | $^{y}$397.0±58.2 |
| None | MM | 10.8±3.6 | 7.0±2.4 | 6.9±1.5 | 53.9±6.4 | 23.3±11.2 | 6.4±5.7 | $^{yb}$27.9±4.0 | $^{yb}$39.9±2.0 | 73.9±18.3 | 363.3±80.8 |
| None | MCM | 9.9±2.8 | 6.1±1.5 | 8.0±5.3 | 53.0±6.4 | 23.7±2.4 | 7.8±5.5 | 25.5±9.4 | $^{a}$24.9±5.3 | $^{a}$67.3±3.7 | 334.7±12.8 |
| Trad | M | 10.6±1.8 | 7.2±0.7 | $^{b}$12.6±3.4 | $^{yb}$74.9±14.6 | $^{b}$28.0±0.7 | 10.2±1.8 | 20.1±5.2 | $^{b}$35.4±6.5 | 66.4±14.4 | 331.1±76.1 |
| Trad | MC | 12.8±3.0 | 5.7±1.1 | $^{a}$5.7±2.7 | $^{a}$49.6±9.4 | 23.9±10.0 | 5.9±5.2 | 37.5±34.3 | 42.4±20.4 | 61.7±15.1 | $^{x}$296.4±34.8 |
| Trad | MM | 9.9±1.1 | $^{y}$6.6±0.1 | $^{a}$6.2±1.6 | $^{a}$51.1±3.0 | $^{a}$21.7±5.0 | 5.7±5.0 | $^{x}$16.2±5.5 | $^{xa}$22.5±2.7 | 58.7±6.6 | 337.5±54.5 |
| Trad | MCM | 9.9±1.1 | 6.7±0.05 | 7.0±3.7 | 63.6±30.2 | 24.6±5.0 | 8.0±3.9 | 19.7±5.8 | 27.6±5.8 | 70.0±12.5 | 352.7±53.9 |
| Zonal | M | 11.3±3.0 | 6.5±1.4 | 15.0±14.1 | $^{xa}$52.7±3.6 | 26.0±3.0 | 8.2±2.6 | 21.5±4.7 | $^{xb}$35.7±2.4 | 75.8±19.1 | 383.1±76.3 |
| Zonal | MC | 12.7±2.0 | 6.7±1.4 | 5.7±2.2 | $^{a}$48.9±6.4 | 24.4±2.4 | $^{a}$5.0±2.8 | 43.4±32.5 | $^{b}$40.5±11.5 | 76.5±14.1 | 373.5±66.5 |
| Zonal | MM | 10.2±1.8 | $^{x}$5.6±0.7 | 7.0±2.2 | 51.3±7.5 | 21.0±6.6 | 5.7±4.9 | $^{x}$17.7±2.9 | $^{xa}$23.9±7.9 | 71.8±18.8 | 361.3±58.4 |
| Zonal | MCM | 10.1±1.2 | 5.8±0.9 | 7.3±3.6 | $^{b}$62.0±6.2 | 27.8±4.2 | $^{b}$12.0±3.7 | 42.4±31.1 | 39.0±21.0 | 83.8±27.6 | 415.5±132.9 |

[1] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

### 2.3.4 Effect of tillage and cropping on soil nutrients in the forest agro-ecosystem

Three tillage treatments: NT, ZT and TT and four cropping treatments: sole maize (M), maize-cowpea rotation (MC), maize-mucuna rotation (MM) and maize-cowpea-mucuna relay (MCM) were used in the forest agro-ecosystem.

Univariate analysis of variance found a significant effect of tillage on extractable EOC ($p = 0.098$) and $Mg^{2+}$ ($p = 0.08$). There was no significant effect of cropping or significant interaction of tillage and cropping on any of the extractable nutrients in the forest agro-ecosystem (Table 4).

Table 4. Results of univariate analysis of variance in the Forest agro-ecosystem. EOC = Extractable Organic Carbon. *Significant at p < 0.10 and **Significant at < 0.05. n = 36

| | EOC | | $Mg^{2+}$ | |
|---|---|---|---|---|
| Treatment | F Value | p value | F Value | p value |
| Tillage | 2.56 | **0.098*** | 2.80 | **0.08*** |
| Cropping | 0.16 | 0.92 | 1.45 | 0.25 |
| Tillage x Cropping | 0.78 | 0.59 | 1.14 | 0.37 |

Concentrations of extractable nutrients varied in the forest agro-ecosystem. $NO_3$-N concentrations ranged from 8.6±2.8 to 14.7±4.5 mg $kg^{-1}$, $NH_4$-N concentrations ranged from 8.2±4.0 to 14.6±2.3 mg $kg^{-1}$ and EON concentrations ranged from 14.9±12.7 to 26.6±3.1 mg $kg^{-1}$. $PO_4$-P concentrations ranged from 1.3±0.1 to 7.3±10.3 mg $kg^{-1}$ and EOC concentrations ranged from 80.3±17.2 to 126.9±72.4 mg $kg^{-1}$. Cation concentrations ranged from 45.2±1.7 to 83.9±38.6 mg $Na^{+}$ $kg^{-1}$ from 34.4±7.3 to 51.7±26.2 mg $K^{+}$ $kg^{-1}$, from 260.2±63.7 to 374.5±81.5 mg $Mg^{2+}$ $kg^{-1}$ and from 865±141.5 to 1211.5±395.5 mg $Ca^{2+}$ $kg^{-1}$ (Table 5).

#### 2.3.4.1 Tillage

Although NT did not have a significant effect on extractable N species in the forest agro-ecosystem of Ghana, under ZT, MM plots were found to have significantly higher extractable $NH_4$-N, TEN and EON concentrations compared to MM under TT (Table 5).

Tillage had no significant effect on extractable soil $PO_4$-P, $Na^{+}$, $K^{+}$ or $Ca^{2+}$ in the forest agro-ecosystem (Table 5). NT was found to have significantly higher EOC concentrations under M cropping compared to TT and higher concentrations of EOC with M cropping under ZT (Table 5). Under ZT the MM crop also had significantly higher EOC concentrations compared to the same crops under TT (Table 5). For extractable soil $Mg^{2+}$, ZT had significantly higher concentrations than NT in the MM plots.

#### 2.3.4.2 Cropping

Although cropping had no significant effect on extractable soil $NO_3$-N, $NO_4$-N, $PO_4$-P, $Mg^{2+}$ and $Ca^{2+}$ in the forest agro-ecosystem of Ghana, higher soil EON concentrations were found under MM crops compared to MCM crops under ZT (Table 5). Under NT, M crops (22.2±2.3 mg $kg^{-1}$) had significantly higher EON concentrations compared to MC crops (17.0±2.9 mg $kg^{-1}$). Maize-Mucuna (MM) crops under ZT had significantly higher EOC concentrations (113.5±6.8 mg C $kg^{-1}$) compared to M crops under ZT (89.2±3.4 mg C $kg^{-1}$). For extractable $Na^{+}$, M crop was found to have significantly higher concentrations under MC and MCM crops within TT plots (Table 5).

### 2.3.5 Effect of tillage and cropping on soil nutrients in the forest- guinea savannah transition agro-ecosystem

Three tillage treatments: NT, ZT and TT and four cropping treatments: sole maize (M), maize-cowpea rotation (MC), maize-mucuna rotation (MM) and maize-cowpea-mucuna relay (MCM) were used in the forest-guinea savannah transition agro-ecosystem.

Univariate analysis of variance found a significant effect of tillage on EOC ($p = 0.01$) and the EOC:$PO_4$-P ratio only. A significant effect of cropping was found for $NO_3$-N ($p = 0.053$); there was no interaction of cropping and tillage on any of the extractable nutrients in the forest-guinea savannah transition agro-ecosystem (Table 6).

Table 5. Soil nutrients in the Forest agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (ab) within each tillage groups shows significant effect of cropping at $p<0.05$. Differences in superscript letters (xyz) within cropping groups shows a significant effect of tillage at $p<0.05$. Tillage: None = No Till, Trad = Traditional Tillage and Zonal = Zonal Tillage. Cropping: M = Sole Maize, MC =Maize-Cowpea rotation, MM = Maize-Mucuna rotation and MCM = Maize-Cowpea-Mucuna relay[2]

| Till | Crop | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg kg$^{-1}$ | | | | | | | | | |
| None | M | 8.6±2.8 | 10.4±3.9 | 1.6±0.4 | $^{y}$113.9±9.6 | 41.3±7.6 | $^{b}$22.2±2.3 | 63.8±24.2 | 42.5±9.2 | 329.7±20.9 | 865±141.5 |
| None | MC | 9.2±2.2 | 8.9±2.7 | 3.4±2.8 | 90.0±20.2 | $^{x}$35.1±5.8 | $^{a}$17.0±2.9 | 72.8±41.8 | 45.9±10.8 | 317.5±25.2 | 1098.3±212.1 |
| None | MM | 12.7±5.1 | $^{x}$8.2±4.0 | 1.6±0.4 | $^{x}$99.1±9.0 | 42.4±15.1 | 21.5±15.5 | 45.2±1.7 | 39.2±4.7 | $^{x}$260.2±63.7 | 1191.2±537.7 |
| None | MCM | 9.3±3.6 | 9.8±5.7 | 1.9±0.4 | 126.9±72.4 | 37.1±6.7 | 18.0±4.2 | 53.3±12.2 | 48.9±17.9 | 335.1±41.1 | 1064.4±18.0 |
| Trad | M | 14.7±4.5 | 8.7±4.9 | 1.3±0.3 | $^{x}$89.1±8.6 | 38.3±13.4 | 14.9±12.7 | $^{b}$57.4±4.7 | 34.4±7.3 | 335.9±14.4 | 1066.9±105.3 |
| Trad | MC | 13.0±2.4 | 12.5±7.0 | 1.8±0.6 | 87.2±28.3 | $^{yb}$43.4±3.9 | 17.9±1.7 | $^{a}$49.2±2.6 | 43.2±5.8 | 267.3±71.5 | 1157.1±533.3 |
| Trad | MM | 9.8±2.6 | $^{x}$8.4±3.8 | 1.9±0.8 | $^{x}$82.5±15.5 | $^{xa}$34.1±5.4 | $^{x}$15.8±2.9 | 45.4±11.4 | 48.1±26.1 | 294.5±43.3 | 1211.5±395.5 |
| Trad | MCM | 11.0±2.4 | 10.4±5.4 | 1.9±0.7 | 80.3±17.2 | 41.6±14.2 | 20.2±8.8 | $^{a}$45.3±5.6 | 51.7±26.2 | 326.9±40.1 | 1048.4±211.3 |
| Zonal | M | 12.2±6.5 | 10.4±5.2 | 1.3±0.1 | $^{xa}$89.2±3.4 | $^{a}$38.4±11.0 | 15.9±10.5 | 57.0±12.1 | $^{a}$36.7±2.9 | 317.1±39.5 | 1075.7±223.4 |
| Zonal | MC | 11.8±2.5 | 11.8±4.8 | 7.3±10.3 | 106.6±21.7 | 41.5±16.5 | 17.9±13.1 | 83.9±38.6 | 42.7±13.7 | 341.8±35.5 | 1070.1±323.5 |
| Zonal | MM | 14.2±4.0 | $^{yb}$14.6±2.3 | 1.4±0.2 | $^{yb}$113.5±6.8 | $^{yb}$55.4±1.7 | $^{yb}$26.6±3.1 | 61.2±28.4 | $^{b}$43.3±3.8 | $^{y}$357.5±41.3 | 1014.2±129.6 |
| Zonal | MCM | 8.6±2.6 | $^{a}$9.0±4.0 | 1.8±1.1 | 101.9±17.3 | $^{a}$37.9±7.7 | $^{a}$20.2±2.5 | 60.2±22.2 | 39.5±7.6 | 374.5±81.5 | 1011.2±63.9 |

[2] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

Table 6. Result of univariate analysis of variance in the forest-guinea savannah transition agro-ecosystem. EOC = Extractable Organic C. *Significant at $p < 0.10$ and **Significant at < 0.05. n = 36

| | $NO_3$-N | | EOC | | EOC:$PO_4$-P Ratio | |
|---|---|---|---|---|---|---|
| Treatment | F Value | p value | F Value | p value | F Value | p value |
| Tillage | 0.68 | 0.51 | 5.46 | **0.011*** | 2.56 | **0.099*** |
| Cropping | 2.92 | **0.053*** | 0.75 | 0.53 | 1.02 | 0.4 |
| Tillage x Cropping | 0.7 | 0.65 | 0.97 | 0.46 | 0.45 | 0.84 |

Concentrations of extractable nutrients in the forest-guinea savannah agro-ecosystem were variable. $NO_3$-N concentrations ranged from 2.6±0.1 to 3.9±0.4 mg $kg^{-1}$, $NH_4$-N concentrations ranged from 4.3±0.5 to 8.3±3.8 mg $kg^{-1}$ and EON concentrations ranged from 4.0±6.9 to 23.8±9.4 mg $kg^{-1}$. $PO_4$-P concentrations ranged from 4.4±1.4 to 8.0±4.5 mg $kg^{-1}$ and EOC concentrations ranged from 42.0±11.3 to 67.4±5.0 mg $kg^{-1}$. Cation concentrations ranged from 21.6±2.5 to 50.3±29.3 mg $Na^+$ $kg^{-1}$ from 18.6±2.3 to 35.3±22.8 mg $K^+$ $kg^{-1}$, from 61.3±6.9 to 101.2±30.8 mg $Mg^{2+}$ $kg^{-1}$ and from 406.9±42.0 to 650.3±459.4 mg $Ca^{2+}$ $kg^{-1}$ (Table 7).

2.3.5.1 Tillage

In the forest-guinea savannah transition agro-ecosystem, tillage had no significant effect on extractable $NH_4$-N, $PO_4$-P, $Na^+$, and $K^+$. However, NT had significantly higher concentrations of NO3-N and EON than ZT under MM crops (Table 7).

For EOC, findings were similar to those observed in the forest agro-ecosystem. The NT treatment resulted in significantly higher concentrations of EOC under MM compared to MM crops under TT and ZT treatments (Table 7).

For extractable soil $Mg^{2+}$ in the forest-guinea savannah transition zone, ZT treatments with M crops had significantly higher extractable $Mg^{2+}$ than M crops with TT treatment (Table 7). While for M cropping, ZT had significantly higher extractable $Mg^{2+}$ than TT. ZT treatments under MM also had significantly higher extractable $Ca^{2+}$ than TT under MM (Table 7).

Table 7. Soil nutrients in the Forest-Guinea Savannah Transition agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (ab) within each tillage groups shows significant effect of cropping at $p<0.05$. Differences in superscript letters (xyz) within cropping groups shows a significant effect of tillage at $p<0.05$. Tillage: None = No Till, Trad = Traditional Tillage and Zonal = Zonal Tillage. Cropping: M = Sole Maize, MC =Maize-Cowpea rotation, MM = Maize-Mucuna rotation and MCM = Maize-Cowpea-Mucuna relay[3]

| Till | Crop | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg kg$^{-1}$ | | | | | | | | | |
| None | M | 3.6±0.9 | 6.2±2.0 | 5.7±2.7 | $^{a}$56.1±6.3 | 20.4±8.5 | 10.6±8.1 | 21.6±2.5 | 35.3±22.8 | 80.8±26.9 | 567.9±303.7 |
| None | MC | $^{a}$2.9±0.4 | 4.9±0.3 | 4.8±0.4 | $^{a}$55.7±8.4 | $^{a}$13.8±8.8 | 6.0±9.5 | 43.1±30.3 | 21.9±8.5 | $^{a}$63.8±13.4 | 420.8±92.8 |
| None | MM | $^{yb}$3.7±0.5 | 8.3±3.8 | 4.4±1.4 | $^{yb}$67.4±5.0 | $^{yb}$35.8±12.3 | $^{yb}$23.8±9.4 | 49.8±28.0 | 30.1±10.8 | $^{yb}$105.7±6.7 | 631.7±212.1 |
| None | MCM | 3.7±0.9 | 6.7±3.8 | 5.7±2.9 | 54.5±13.2 | $^{a}$14.2±11.6 | $^{a}$4.0±6.9 | 29.4±7.2 | 30.7±11.2 | 90.2±31.9 | 714.4±454.2 |
| Trad | M | $^{c}$3.8±0.4 | 5.6±1.6 | 5.7±0.5 | 46.9±6.9 | 20.1±11.3 | 10.8±9.3 | 50.3±29.3 | $^{b}$28.2±4.5 | $^{xa}$61.3±6.9 | 406.9±42.0 |
| Trad | MC | $^{a}$2.6±0.1 | $^{a}$4.9±0.2 | 5.2±0.9 | 53.7±11.1 | 18.6±9.6 | 11.2±9.7 | 27.0±2.5 | $^{a}$19.2±0.9 | 74.0±19.3 | 410.7±106.3 |
| Trad | MM | 3.9±2.1 | $^{b}$5.7±0.2 | 4.9±0.5 | $^{x}$49.8±5.0 | 20.4±7.5 | 10.9±9.5 | 30.6±3.0 | $^{b}$24.9±4.0 | $^{b}$90.6±22.3 | $^{x}$418.9±49.8 |
| Trad | MCM | $^{b}$3.0±0.3 | $^{a}$4.3±0.5 | 4.8±1.0 | 42.0±11.3 | 12.6±10.0 | 5.3±9.3 | 23.8±7.0 | $^{a}$18.6±2.3 | $^{b}$76.2±6.5 | 438.9±83.6 |
| Zonal | M | $^{b}$3.9±0.4 | 7.7±4.8 | 8.0±4.5 | 47.9±6.1 | 17.1±12.8 | 5.6±8.1 | 33.8±12.1 | 27.3±8.5 | $^{y}$101.2±30.8 | 650.3±459.4 |
| Zonal | MC | $^{a}$2.8±0.4 | 6.6±2.6 | 5.1±1.1 | 51.3±13.4 | 26.6±20.3 | 17.3±18.2 | 44.1±34.3 | 22.2±5.3 | 85.2±12.4 | $^{a}$444.4±51.2 |
| Zonal | MM | $^{ax}$2.9±0.3 | 7.4±3.5 | 4.7±1.1 | $^{x}$44.5±3.7 | $^{x}$15.6±11.4 | $^{x}$5.4±8.2 | 31.3±12.6 | 20.1±3.0 | $^{x}$88.4±10.9 | $^{yb}$530.9±27.4 |
| Zonal | MCM | $^{a}$2.8±0.3 | 6.8±3.2 | 4.6±0.1 | 49.5±7.7 | 22.7±13.5 | 13.0±10.7 | 27.8±4.3 | 22.9±4.5 | 80.1±9.0 | $^{a}$408.6±44.7 |

[3] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

2.3.5.2 Cropping

In the forest-guinea savannah agro-ecosystem, cropping had a significant effect on extractable soil $NO_3$-N. Under TT, soil under M crops had significantly higher concentrations of $NO_3$-N (3.8±0.4 mg $kg^{-1}$) than soil under MCM crops (3.0±0.3 mg $kg^{-1}$) and MC crops (2.6±0.1 mg $kg^{-1}$). This was similar to ZT where soil under M cropping had significantly higher $NO_3$-N concentrations (3.9±0.4 mg $kg^{-1}$) compared to soil under MC cropping (2.8±0.4 mg $kg^{-1}$), MM cropping (2.9±0.3 mg $kg^{-1}$) and MCM cropping (2.8±0.3 mg $kg^{-1}$). However, in the NT plots, soil under MM crops had significantly higher extractable $NO_3$-N than soil under MC crops. In the TT plots, extractable $NO_4$-N was significantly higher under MM cropping compared to MC and MCM cropping systems (Table 7). Soil under MM cropping also had significantly more EON than soil under MCM cropping with NT (Table 7). In the forest-Guinea savannah transition region, soils under MM cropping to have a significantly higher concentration of EOC compared to M and MC cropping systems with NT (Table 7). For extractable $K^+$, there was only a significant difference in the TT plots where soil under M and MM cropping had significantly higher extractable $K^+$ than soil under MC and MCM cropping (Table 7). Results were different for extractable $Mg^{2+}$, where in the NT plots, soil under MM had significantly higher concentrations of extractable $Mg^{2+}$ than soil under MC cropping (Table 7). This was similar to the TT plots where soil under MM and MCM cropping had significantly higher extractable $Mg^{2+}$ than soil under M cropping (Table 7). MM cropping also had a significant effect on extractable soil $Ca^{2+}$ compared to soil under MC and MCM cropping in the ZT plots.

### 2.3.6 Effect of tillage and cropping on soil nutrients in the guinea savannah agro-ecosystem

Three tillage treatments: NT, ZT and TT and four cropping treatments: sole maize (M), maize-cowpea rotation (MC), maize-cowpea intercrop (MCI) and cowpea-maize rotation (CM) were used in the Guinea savannah agro-ecosystem. Cropping treatments were different in the Guinea savannah agro-ecosystem due to a shorter growing season and the fact that mucuna will not grow in the Guinea savannah agro-ecosystem.

Univariate analysis of variance, performed using tillage and cropping as fixed factors, found that neither tillage nor cropping had a significant effect on extractable soil nutrients in this agro-ecosystem. There was however an interaction (tillage x cropping) effect on extractable soil EON concentrations (Table 8).

Table 8. Results of univariate analysis of variance in the Guinea savannah agro-ecosystem. EON=Extractable Organic N. *Significant at $p < 0.10$ and **Significant at < 0.05. n = 36

| | EON | |
|---|---|---|
| Treatment | F Value | p value |
| Tillage | 1.4 | 0.26 |
| Cropping | 1.98 | 0.14 |
| Tillage x Cropping | 3.13 | **0.02**** |

Concentrations of extractable soil nutrients were variable in the Guinea savannah agro-ecosystem. $NO_3$-N ranged from 13.2±1.6 to 22.0±6.0 mg kg$^{-1}$, $NH_4$-N concentrations ranged from 5.8±1.6 to 8.7±3.2 mg kg$^{-1}$ and EON concentrations ranged from 0.0±0.0 to 9.3±1.2 mg kg$^{1}$ (Table 9). $PO_4$-P concentrations ranged from 1.2±0.1 to 3.3±2.5 mg kg$^{-1}$ and EOC concentrations ranged from 43.5±9.0 to 65.7±40.2 mg kg$^{-1}$ (Table 9). Cation concentrations ranged from 17.3±9.2 to 60.4±28.3 mg $Na^+$ kg$^{-1}$ from 37.4±5.5 to 58.5±11.9 mg $K^+$ kg$^{-1}$, from 60.7±15.1 to 102.7±52.6 mg $Mg^{2+}$ kg$^{-1}$ and from 226.9±74.4 to 356.5±56.5 mg $Ca^{2+}$ kg$^{-1}$ (Table 9).

#### 2.3.6.1 Tillage

Significantly higher extractable soil $NO_4$-N was observed in soil under CM cropping with NT compared to soil under CM cropping with ZT. (Table 9). NT and ZT were also found to have a significant effect on extractable EON concentrations under M cropping compared to TT, while ZT and TT had significantly higher extractable EON concentrations compared to NT in the soil under MCI and CM crops (Table 9). While tillage did not have a significant effect on EOC, $PO_4$-P, $K^+$, $Mg^{2+}$, or $Ca^{2+}$ concentrations in the Guinea-savannah region, NT had significantly higher extractable $Na^+$ concentrations compared to TT under CM crops (Table 9).

#### 2.3.6.2 Cropping

In the guinea-savannah agro-ecosystem, soil beneath MCI crops had significantly higher extractable $NO_3$-N than soil under MC crops with ZT. However, soil below CM crops (9.3±1.2 mg N $kg^{-1}$) had significantly higher extractable EON compared to soil below MC crops (2.6±2.3 mg N $kg^{-1}$) under ZT. Soils exposed to TT under M crops displayed significantly lower EON concentrations compared to all other cropping systems (Table 9). In the Guinea savannah agro-ecosystem, soils exposed to TT under MCI cropping had significantly higher concentrations of extractable $PO_4$-P (1.7±0.3 mg $kg^{-1}$) compared to CM cropping (1.2±0.1 mg $kg^{-1}$). Within the TT plots, soil beneath CM cropping displayed significantly higher EOC concentrations compared to soil beneath M cropping systems (Table 9).

While cropping did not have a significant effect on extractable $Na^+$ in the Guinea savannah region, under TT, significantly higher extractable $K^+$ concentration was observed in soils under M crops compared to soils under MCI crops (Table 9). For NT plots, soils under MC crops had significantly higher extractable $K^+$ concentrations compared to soils under MCI crops (Table 9). Lastly, under ZT, soils under MC crops had significantly more $Ca^{2+}$ than soils under MCI crops.

Table 9. Soil nutrients in the Guinea Savannah agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (ab) within each tillage groups shows significant effect of cropping at $p<0.05$. Differences in superscript letters (xyz) within cropping groups shows a significant effect of tillage at $p<0.05$. Tillage: None = No Till, Trad = Traditional Tillage and Zonal = Zonal Tillage. Cropping: M = Sole Maize, MC =Maize-Cowpea rotation, MCI = Maize-Cowpea Intercrop and CM = Cowpea-Maize rotation[4]

| Till | Crop | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg kg$^{-1}$ | | | | | | | | | |
| None | M | 14.4±5.0 | 6.2±1.1 | 2.7±2.6 | 43.5±9.0 | 26.0±5.0 | $^{y}$5.5±2.7 | 41.3±46.0 | 41.0±15.3 | 88.3±41.1 | 262.1±42.2 |
| None | MC | 17.9±7.8 | 7.1±1.0 | 1.7±0.5 | 51.7±8.2 | 29.9±13.7 | 5.5±4.9 | 38.4±38.1 | 39.9±23.4 | 79.1±12.2 | 302.2±61.7 |
| None | MCI | 22.0±6.0 | 6.6±1.4 | 1.4±0.2 | 46.2±9.5 | 28.9±5.0 | $^{x}$2.3±4.0 | 19.3±11.4 | $^{a}$37.4±5.5 | 90.2±52.0 | 299.3±125.8 |
| None | CM | 20.9±12.8 | $^{y}$6.7±0.5 | 2.1±1.5 | 52.3±16.2 | 27.5±11.1 | $^{x}$2.3±4.0 | $^{y}$60.4±28.3 | $^{b}$58.5±11.9 | 88.7±39.0 | 264.0±67.9 |
| Trad | M | 20.5±7.9 | 6.4±1.4 | 2.2±1.3 | $^{a}$44.2±8.5 | 23.2±6.5 | $^{xa}$0.0±0.0 | 26.1±8.5 | $^{b}$56.4±8.6 | 79.5±8.0 | 295.0±67.2 |
| Trad | MC | 13.4±5.3 | 7.5±1.6 | 1.5±0.6 | 44.3±15.2 | 27.0±6.9 | $^{b}$6.1±5.0 | 23.8±4.2 | 46.3±16.4 | 68.4±16.3 | 270.1±55.1 |
| Trad | MCI | 14.4±7.6 | 5.8±1.6 | $^{b}$1.7±0.3 | 48.5±9.3 | 29.1±7.3 | $^{yb}$8.9±0.5 | 19.8±2.0 | $^{a}$41.6±2.4 | 77.0±24.3 | 272.8±65.5 |
| Trad | CM | 14.3±4.9 | 7.0±1.2 | $^{a}$1.2±0.1 | $^{b}$63.0±8.9 | 29.8±4.6 | $^{yb}$8.5±2.3 | $^{x}$20.8±0.9 | 45.5±7.7 | 102.7±52.6 | 326.3±61.0 |
| Zonal | M | 16.9±11.4 | 5.8±0.6 | 1.8±0.5 | 46.0±10.8 | 25.9±6.8 | $^{y}$4.3±4.1 | 17.3±9.2 | 48.2±12.5 | 76.5±26.1 | 267.7±54.2 |
| Zonal | MC | $^{a}$13.2±1.6 | 7.5±2.4 | 1.9±0.4 | 45.7±10.9 | $^{a}$22.7±3.8 | $^{a}$2.6±2.3 | 38.4±30.3 | 41.9±8.4 | 84.9±14.9 | $^{b}$356.5±56.5 |
| Zonal | MCI | $^{b}$17.5±3.1 | 8.7±3.2 | 2.2±0.7 | 65.7±40.2 | $^{b}$32.9±6.9 | $^{y}$6.7±2.8 | 25.0±8.9 | 47.9±16.9 | 79.2±27.7 | 266.5±69.6 |
| Zonal | CM | 16.7±6.4 | $^{x}$5.8±0.2 | 3.3±2.5 | 55.0±12.4 | 31.8±7.1 | $^{yb}$9.3±1.2 | 32.4±24.9 | 46.1±18.0 | 60.7±15.1 | $^{a}$226.9±74.4 |

[4] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

### 2.3.7 Modeling soil nutrient status under tillage and cropping

No strong and significant predictive models were able to be constructed using backward stepwise regression analysis with agro-ecosystem, tillage or cropping as predictive variables for extractable nutrients in the whole agro-ecosystem dataset. Only a significant 28% of the variance in $PO_4$-P concentrations could be explained by agro-ecosystem type and cropping practice ($R^2 = 0.28$; Adj $R^2 = 0.25$; $p = 0.001$).

No strong and significant predictive model using tillage or cropping was observed within each agro-ecosystem either (Table 10). Cropping explained 33% of the variance in $NO_3$-N concentrations in the coastal savannah ($p = 0.05$), 31% and 35% of the variance in $K^+$ in the coastal savannah and forest agro-ecosystems ($p = 0.04$-$0.06$), respectively, and 31% of the variance in $PO_4$-P in the forest-Guinea savannah transition agro-ecosystem ($p = 0.06$). Tillage was the important predictor for EOC and $K^+$ in the transition agro-ecosystem (Table 10). Between 42% and 45% of the variance in EOC concentration was explained by tillage in the forest-Guinea savannah transition and by cropping in the Guinea savannah, respectively (Table 10).

Table 10. Predictive models for soil nutrients within agro-ecosystems in Ghana. EOC=Extractable Organic C. Significance was determined at $p < 0.10$

| | | Model Coefficients | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Agro-Ecosystem | Soil Extract | Constant | Tillage | Cropping | $R^2$ | Adj $R^2$ | F Value | p |
| Coastal Savannah | $NO_3$-N | 14.982 | | -1.36 | 0.33 | 0.27 | 4.96 | 0.05 |
| | $K^+$ | 44.943 | | -3.946 | 0.31 | 24 | 4.49 | 0.06 |
| Forest | $K^+$ | 36.515 | | 2.598 | 0.35 | 0.29 | 5.49 | 0.04 |
| Transition | $PO_4$-P | 6.462 | | -0.463 | 0.31 | 0.24 | 4.5 | 0.06 |
| | EOC | 61.727 | -5.058 | | 0.42 | 0.36 | 7.27 | 0.02 |
| | $K^+$ | 31.494 | -3.188 | | 0.27 | 0.2 | 3.73 | 0.08 |
| Guinea Savannah | EOC | 39.818 | | 4.281 | 0.45 | 0.4 | 8.32 | 0.02 |

### 2.3.8 Correlations among extractable soil nutrients

Irrespective of tillage and cropping treatments and agro-ecosystem type, significant positive correlations among extractable soil nutrients were observed over all the farmer fields in Ghana (Table 6). $NO_3$-N was significantly correlated with $K^+$ ($R = 0.75$; $p < 0.01$), and $NH_4$-N significantly correlated with EOC ($R = 0.80$; $p < 0.01$), DON ($R = 0.70$; $p < 0.01$). $Na^+$ ($R= 0.65$; $p < 0.01$), $K^+$ ($R = 0.38$; $p < 0.01$), $Mg^{2+}$ ($R = 0.76$; $p < 0.01$) and $Ca^{2+}$ ($R = 0.76$; $p < 0.01$). EOC was significantly correlated with EON ($R = 0.82$; $p < 0.01$) and $Na^+$, $Mg^{2+}$ and $Ca^{2+}$ (Table 11).

The strong and significant positive correlations were not so strong or lost entirely when examining correlations within each agro-ecosystem.

Table 11. Correlations (r) among extractable soil nutrients across the four agro-ecosystems studied in Ghana. EOC=Extractable Organic C, EON=Extractable Organic N. *Significant at $p < 0.05$ **Significant at $p < 0.01$. n = 48.

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | 0.17 | 0.03 | -0.26 | -0.05 | **0.75**** | 0.05 | -0.16 |
| $NH_4$-N | | **0.80**** | **0.70**** | **0.65**** | **0.38**** | **0.82**** | **0.76**** |
| EOC | | | **0.82**** | **0.69**** | **0.31*** | **0.91**** | **0.84**** |
| EON | | | | **0.65**** | 0.05 | **0.78**** | **0.77**** |
| $Na^+$ | | | | | 0.26 | **0.76**** | **0.70**** |
| $K^+$ | | | | | | **0.33*** | 0.16 |
| $Mg^{2+}$ | | | | | | | **0.93**** |

2.3.8.1 Coastal savannah agro-ecosystem nutrient correlations

The positive correlation between $NO_3$-N and $K^+$ observed across the whole dataset remained strong and significant within the coastal savannah agro-ecosystem ($r = 0.65$; $p < 0.05$) but all correlations with $NH_4$-N were lost (Table 12). The positive correlation between EOC and EON remained strong and significant ($r = 0.73$; $p < 0.01$). The weak but significant positive correlation between $K^+$ and $Mg^{2+}$ observed across all the ecosystems was increased in the coastal savannah ($R = 0.58$; $p < 0.05$) and the strong positive relationship between $Mg^{2+}$ and $Ca^{2+}$ observed across all ecosystems remained strong (Table 12).

Table 12. Correlations (r) among extractable soil nutrients within the coastal savannah agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *Significant at $p < 0.05$ **Significant at $p < 0.01$. n = 12.

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | 0.38 | -0.15 | -0.30 | 0.02 | **0.65*** | 0.31 | 0.13 |
| $NH_4$-N | | 0.30 | -0.02 | -0.23 | 0.19 | -0.09 | -0.04 |
| EOC | | | **0.73**** | -0.22 | 0.06 | 0.12 | 0.09 |
| EON | | | | 0.16 | 0.00 | 0.19 | 0.28 |
| $Na^+$ | | | | | 0.43 | 0.17 | 0.10 |
| $K^+$ | | | | | | **0.58*** | 0.32 |
| $Mg^{2+}$ | | | | | | | **0.91**** |

2.3.8.2 Forest agro-ecosystem nutrient correlations

Most of the strong and significant positive correlations observed across all agro-ecosystems (Table 11) were lost when examining the forest agro-ecosystem alone (Table 13). The only significant correlation was between $Mg^{2+}$ and $Ca^{2+}$ but strangely it was an inverse correlation where increases in extractable soil $Ca^{2+}$ resulted in decreases in extractable soil $Mg^{2+}$ (Table 13).

Table 13. Correlations (r) among extractable soil nutrients within the forest agro-ecosystem. EOC=Extractable Organic C, EON= Extractable Organic N.*Significant at p < 0.05 **Significant at p < 0.01. n = 12.

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | 0.41 | -0.21 | 0.07 | -0.12 | -0.47 | -0.21 | 0.28 |
| $NH_4$-N | | 0.29 | 0.54 | 0.26 | 0.11 | 0.23 | -0.29 |
| EOC | | | 0.49 | 0.34 | 0.02 | 0.42 | -0.51 |
| EON | | | | 0.00 | 0.13 | 0.24 | -0.44 |
| $Na^+$ | | | | | -0.18 | 0.51 | -0.41 |
| $K^+$ | | | | | | -0.04 | 0.08 |
| $Mg^{2+}$ | | | | | | | **-0.68**** |

2.3.8.3 Forest-guinea savannah transition agro-ecosystem nutrient correlations

The transition agro-ecosystems displayed correlations among extractable nutrients most similar to the correlations observed across the four agro-ecosystems in Ghana although some correlations among nutrients were lost (Table 14). $NO_3$-N maintained its strong positive correlation with $K^+$ ($R = 0.77$; $p < 0.01$) and $NH_4$-N maintained its strong positive correlation with $Mg^{2+}$ and $Ca^{2+}$ (Table 14). Moderate but significant positive correlations were observed between EOC and EON ($R = 0.64$; $p < 0.05$) and between $Ca^{2+}$ and $Mg^{2+}$ (Table 14). The transition agro-ecosystem was the only one where a moderate but significant positive correlation between $K^+$ and $Ca^{2+}$ was observed (Table 14).

Table 14. Correlations (r) among extractable soil nutrients within the Forest-Guinea Savannah transition agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *Significant at $p < 0.05$ **Significant at $p < 0.01$. n = 12.

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | 0.36 | 0.18 | -0.01 | 0.15 | **0.77**** | 0.42 | 0.56 |
| $NH_4$-N | | 0.37 | 0.38 | 0.27 | 0.42 | **0.80**** | **0.66*** |
| EOC | | | **0.64*** | 0.36 | 0.51 | 0.33 | 0.38 |
| EON | | | | 0.50 | 0.19 | 0.30 | -0.08 |
| $Na^+$ | | | | | 0.09 | -0.03 | -0.05 |
| $K^+$ | | | | | | 0.30 | **0.62*** |
| $Mg^{2+}$ | | | | | | | **0.71*** |

### 2.3.8.4 Guinea savannah nutrient correlations

Most of the correlations among extractable nutrients observed across the full agro-ecosystem dataset were lost in the Guinea savannah agro-ecosystem (Table 15). Only a moderate but significant positive correlation between $Mg^{2+}$ and $Ca^{2+}$ remained ($R = 0.60$; $p < 0.05$).

Table 15. Correlations (R) among extractable soil nutrients within the guinea savannah transition agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *Significant at $p < 0.05$ **Significant at $p < 0.01$. n = 12.

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | -0.10 | 0.01 | -0.57 | 0.16 | 0.37 | 0.10 | -0.17 |
| $NH_4$-N | | 0.47 | -0.06 | 0.07 | 0.01 | 0.16 | 0.34 |
| EOC | | | 0.52 | -0.05 | 0.12 | 0.19 | -0.06 |
| EON | | | | -0.27 | -0.36 | -0.24 | -0.35 |
| $Na^+$ | | | | | 0.34 | 0.12 | -0.07 |
| $K^+$ | | | | | | -0.06 | -0.26 |
| $Mg^{2+}$ | | | | | | | **0.60*** |

## 2.4 Discussion

Researchers have agreed that smallholder farmers across Africa must increase their productivity in order to achieve the millennium development goals (MDG) (Andriesse et al., 2007; Giller et al., 2011). However, studies across West Africa have failed to agree on what the best technologies and agronomic practices are in order to maintain or increase soil fertility, and thus help increase yields (Lal, 1976; Niemeijer et al., 2002; Smaling et al., 1997; Vanlauwe et al., 2006; Giller et al., 2009). The experiment examining tillage and cropping in four agro-ecosystems in Ghana attempted to better address some of the criticisms facing past CA research by better mimicking the realities facing smallholder farmer across Ghana. Results after two years of treatments indicated that agro-ecosystem has the largest effect on soil nutrient status while reducing tillage and implementing a rotation or intercrop has minimal effect when including all agro-ecosystems in analysis.

### 2.4.1 Tillage effects on soil nutrients

When assessing the effect of tillage on extractable soil nutrients across all four Ghanaian agro-ecosystems, this study found that there was no overall significant effect of tillage on any of the extractable nutrients examined. Although NT and ZT tended to have higher concentrations of soil nutrients in the coastal savannah, forest and forest-Guinea savannah transition zone, results were not statistically significant. However, when assessing each agro-ecosystem individually, results indicated that reduced tillage, either through NT or ZT, is beginning to have an effect on soil EOC concentrations in the forest and forest-Guinea savannah agro-ecosystem and on extractable soil $Mg^{2+}$ concentrations in the coastal savannah and forest agro-ecosystem.

The variability in results suggests that the type of tillage practice adopted should be based on the agro-ecosystem. Similar conclusions were made by Pouya et al. (2013) when examining different management practices for cotton farming in Burkina Faso, W. Africa. Pouya et al. (2013) reported that motorized tillage or animal traction was better for farmer fields in central Burkina Faso while minimal tillage was a better option for maintaining soil fertility in western Burkina Faso. In contrast, Omonode et al., (2006) reported that NT and short-term no-till tillage practices resulted in more organic C in Burkina Faso compared to other tillage practices.

While this study in Ghana only examined soil EOC rather than soil C, there has been growing evidence on the importance of SOC in a multitude of African farming systems over the last 20 years (Lal, 2006). In general, research across Africa has demonstrated that adopting NT will increase SOM content in surface soil horizons, which may result in higher concentrations of soil nutrients compared to plowed fields (Lal, 1976). However, results are inconclusive when assessing the effects of conservation agriculture on carbon sequestration across the world (Ouedraogo et al., 2006; Giller at al., 2009; Govaerts et al., 2009). Nevertheless, one of the bigger issues facing soil C sequestration in West African soils is the removal of crop residue for livestock feeding or fuel (Lahmar et al., 2012). Furthermore, Rasmussen et al. (1991) suggested that due to the recognition that soil erosion, tillage practices, drainage as well as residue removal may reduce C input into the soil, and thus reduce SOC; it is difficult therefore to attribute any increase in soil C to any one practice. Nevertheless, the results of this Ghanaian study were comparable to findings by Vaagen et al. (2005) who reported that the largest potential for increasing SOC was through the establishment of natural or improved fallow systems. Fallow systems are particularly beneficial in areas such as the forest agro-ecosystem where there is a high turnover of biomass. Here, the adoption of NT could be viewed as a fallow system where there is minimal soil disturbance. Furthermore, since slash and burn is the traditional land preparation system in the forest agro-ecosystem of Ghana, Vaagen et al.'s (2005) report that biomass burning significantly reduces SOC in the upper few centimeters of soil but has little impact below 10 – 20 cm depth, could help explain why there is a significant difference between no tillage and traditional tillage practices in the forest zone after only two years of treatments. In general, the highest concentration of SOC in tropical forest soils are observed in the 0-20cm depth, this SOC pool is also more labile than SOC in the subsoil and may be prone to change after deforestation or burning (Vaagen et al., 2005). Since a fire can affect the physical, chemical, mineralogical and biological properties of soil (Certini, 2005), the negative effects of repetitive burning of plots under current slash and burn practices in the forest agro-ecosystem of Ghana could explain why there are higher soil EOC concentrations under NT and ZT practices compared to TT (slash and burn). Although, this hypothesis was not tested in the forest agro-ecosystem, it seems to be a plausible explanation for the difference in soil EOC concentrations.

### 2.4.2 Cropping effects on soil nutrients

Historically, the majority of traditional cropping systems have been able to maintain soil fertility and provide stable yields (Steiner, 1991). Then again, most of these cropping systems relied on a prolonged fallow period to restore soil fertility (Steiner, 1991). Due to growing population densities, and a shortage of arable land, these fallow periods have decreased and improved fallow systems, agro-forestry systems, intercropping, crop rotations and soil conservation methods have become popular practices in order to sustain yields in more intense cropping systems (Steiner, 1991). These methods aim to make use of recycling nutrients through nutrient pumping via trees and bushes (e.g. Verbree et al. 2014), biological nitrogen fixation (Franke et al., 2014), mycorrhizae, as well as other external inputs.

When assessing the effect of cropping system on extractable soil nutrients across all four Ghanaian agro-ecosystems, this study found that there was no overall significant effect of cropping on any of the extractable nutrients examined. However, when assessing each agro-ecosystem individually, results indicated that the cropping system was beginning to have an effect on $PO_4$-P and $K^+$ in the coastal savannah agro-ecosystem and $NO_3$-N in the forest-guinea savannah agro-ecosystem.

The uses of legumes in crop rotation across sub-Saharan Africa have been shown to increase biological N-fixation (Dakora et al. 1997). However, in my study there were no observed significant differences between cropping systems after two years. Possible reasons for the lack of observed significant differences could be due to nutritional, genetic and environmental factors relating to both the host plant and its microsymbiont (Dakora et al. 1997). Short term research in the northern Guinea savannah region of Ghana assessed the effects of rotation maize (*Zea mays*) and cowpea (*Vigna unguiculata*) on yield and the uptake of N and P by maize found that yields and nutrient accumulation through N and P uptake of maize were larger in rotation than in monocropping, independent of the amount of N or P applied (Horst et al., 1994). However, the soil nutrient accumulation experienced under rotation cropping was attributed to the cowpea crop residue being left on the field while all above ground biomass of maize was removed after cropping (Horst et al., 1994). Leaving cowpea crop residue on the field is also attributed to higher potential net N mineralization and higher nitrate concentration in the topsoil at the beginning of the cropping periods under maize after cowpea on the unfertilized plots (Horst et al., 1994).

Assessment of integrated soil management systems in the Guinea savannah of Nigeria found that legume rotations increased soil total N compared to other fallows such as mucuna (Carsky et al. 1999). My findings of increased soil TEN and $K^+$ concentrations under the maize-cowpea rotation support the findings of Carsky et al. (1999). Agboola & Fayemi (1972) also reported that legumes tended to conserve available P and exchangeable $K^+$ in the surface soil in the rainforest zone of Western Nigeria. This is also similar to my findings where the maize-cowpea rotation had significantly higher concentrations of extractable $K^+$ than the maize-mucuna or maize-cowpea-mucuna relay. Possible reasons for the benefit of the maize-cowpea rotation is stated by Hardter & Horst (1991) who found that a maize-cowpea rotation had almost 50 kg $ha^{-1}$ nitrogen in the soil compared to only 18 kg $ha^{-1}$ after a maize/cowpea intercrop. This was attributed to the fact that as an intercrop, maize is planted every year, withdrawing nutrients while also shading the cowpea, causing a reduction in photosynthesis and leading to a shortage of energy and a reduction in the amount of potential N that could be fixed symbiotically. Furthermore, Hardter & Horst (1991) reported that in an intercropped system, cowpea left little residual nitrogen in the soil after harvest.

### 2.4.3 Use of EOC:EON ratio instead of soil C:N ratio

Recently Haney et al. (2012) argued for the use of water extractable organic carbon (WEOC) and organic nitrogen WEON instead of whole soil OC and TN for the examination of soil microbial function. Soil C:N ratios are generally calculated using organic C and total N derived from combustion of whole soil (Aitkenhead-Peterson et al. 2007; Haney et al. 2012) and the C:N ratio can vary considerably among world ecosystems (Aitkenhead & McDowell, 2000). While the use of WEOC and WEON at a 1:10 soil:water ratio as used by Haney et al. (2012) to quantify soil C:N had no significant relationship with whole soil C:N ratio, it was a better predictor of soil N immobilization and mineralization which can be important in studies of soil fertility because of its inherent sensitivity to microbial function in agricultural soils. Years of research formed a consensus that a soil C:N ratio of around 20 tends to be the threshold point where there is no net N mineralization or immobilization (Tate 1995; Bengtston et al. 2003).

The Haney et al. (2012) study reported WEOC:WEON ratios ranging from approximately 10 to just under 80 in sub-tropical agricultural soils of Texas, USA whereas whole soil C:N ratio ranged from approximately 6 to 40. The soils in the Ghanaian study were extracted using a 1:10 soil: 0.1 M HCl extract; yielded EOC:EON ratio's ranging from 36 to 330 in the coastal savannah, 6 to 168 in the forest, 4 to 34 in the transition zone and 13 to 144 in the Guinea savannah agro-ecosystems. Soils in Ghana had slightly lower EOC:EON ratio than the WEOC:WEON ratios reported by Haney et al. (2012) in the forest and forest-Guinea-savannah transition agro-ecosystems and much higher EOC:EON ratios in the coastal savannah zones. As the EOC:EON ratio widens there is an indication of more extractable organic-C relative to extractable organic-N where in many cases the soil C:N ratio would be narrower because inorganic-N is included in that measure. Surprisingly most of the extractable TEN was in the form of inorganic-N in all the agro-ecosystems, which is probably due to the point application of 15-15-15 NPK fertilizer prior to the planting season. Perhaps further work on Ghanaian soil fertility should examine microbial community composition and whether it is as significantly affected under soil tillage and cropping in Ghana as it is with tillage and cropping practices in Texas (Gonzalez-Chavez et al. 2010; Ng et al., 2012). This may help to explain why extractable nutrients varied so much within specific tillage and cropping treatments and agro-ecosystems. An alternative reason for high field variability within specific tillage and cropping treatments may be due to past tillage and cropping use of the fields by the caretaker farmer. Given that this experiment was carried out on local farmer fields, internal heterogeneity of resource allocation, such as fertilizer use and tillage and cropping systems will influence current nutrient levels. Given that farmers generally manage their fields according to their perceived land quality thus varying the timing and intensity of management practices along soil fertility gradients, could help explain the high field variability within specific tillage and cropping treatments (Tittonell et al., 2005).

### 2.4.4 Selection of extract for Ghanaian soils

There are a plethora of recommended extracts for extracting soil nutrients, particularly DOC (Chantigny, 2003; Jones & Willett, 2006; Willett et al., 2004). Choice of extract depends entirely on whether the researcher wishes to quantify plant available nutrients, microbially available nutrients or simply extract all nutrients in a soil whether readily available for plants and soil microbes or not. Carillo-Gonzalez et al. (2013)

examined cold water, hot water, 10 mM $CaCl_2$, 2M KCl and 0.5 M $K_2SO_4$ extracts on the recovery of DOC, DON, $NH_4$-N and $NO_3$-N from dryland agricultural soils in Texas, USA with an average pH of 7.5-7.7. They reported that cold water extracts were most similar to DOC in soil water leachate and hot water extracts most similar to TN in soil water leachate; the leachate of course is what is available to plant roots. The selection of a 0.1M HCl extract for Ghanaian soils was based on their relatively low soil pH and the requirement to have a low ionic strength extract solution which would more likely mimic solution infiltrating the soil. One of the issues that was highlighted in the Carillo-Gonzalez (2013) study was the decoupling of the relationship between EOC and EON with different soil extracts; here, cold water, hot water and 0.5M $K_2SO_4$ extracts maintained the EOC and EON relationship whereas the 10 mM $CaCl_2$ and 2M KCl decoupled the relationship. In this Ghanaian study, the relationship between EOC and EON was significant in the individual agro-ecosystems containing forest but decoupled in the two savannah agro-ecosystems suggesting that the selection of 0.1M HCl as a mild extract reflecting soil solution in Ghanaian soils was appropriate for the forest and forest-Guinea savannah transition agro-ecosystems. Fertilization tends to move soil N species toward inorganic-N ($NH_4$-N and $NO_3$-N) rather than EON and the decoupling of the EOC:EON ratio in savannah soils may illustrate this. This primarily due to higher C concentrations in forest soils compared to grassland soils based on the different soil C:N ratios reported by Aitkenhead and McDowell (2000).What is important to consider is the likelihood of more recalcitrant EON species in agro-ecosystems containing woody plant species relative to herbaceous plant species, which may be a control on maintaining soil nutrient equilibrium.

### 2.4.5 Does a "one size fit all" approach in terms of management practices for soil fertility in Ghana work?

One of the larger problems of food security in developing countries is the "one size fits all" approach where farmers are advised to adopt specific tillage, cropping and fertilization practices with no regard of the ecosystem in which they are farming. While three of the four soils in the Ghana study were lixisols there were some fundamental differences in soil pH, type of parent material parent material (igneous, metamorphic and two sedimentary), climate and annual precipitation. Overall, concentrations of all extractable soil nutrients were significantly affected by agro-ecosystem type in this study irrespective of tillage and cropping practices suggesting a greater need for specific ecosystem type management for smallholder farms. Similar conclusions were made by Niemeijer et al. (2002) when comparing agricultural productivity across a range of provincial population densities in Burkina Faso. Using a stepwise regression analysis, Niemeijer et al. (2002) revealed that agricultural productivity is mainly determined by environmental conditions. Furthermore, long-term average rainfall explained more than 80 percent of the explained variance in agricultural productivity, while productivity has little correlation to rural population density (which is a factor of pressure on resources) or animal traction (technology) (Niemeijer et al., 2002). Given that soil fertility is not a static feature, but dynamic, constantly changing due to the interplay of different physical, chemical, biological, and anthropogenic processes (Smaling et al., 1997), it should not be a surprise that agro-ecosystem has such a significant effect on extractable soil nutrients. Furthermore, given the diversity of soil types, climates and agricultural production systems found across both Ghana and Africa, it must be reiterated that agriculture must be compatible with the ecological environment in which it resides.

### 2.4.6 Modeling soil nutrients

Based on the need to know soil nutrient status in developing countries under certain agro-ecosystem and tillage and cropping management for supplemental fertilizer recommendation it was decided to examine these variables as predictors of soil nutrient status. The reasoning behind this move was to find predictors of soil nutrient status to reduce costs of soil testing in developing countries. No strong and significant predictive models could be constructed using a backward stepwise regression analysis with agro-ecosystem, tillage or cropping as predictive variables for extractable nutrients in the whole agro-ecosystem dataset. This was unsurprising given the differences in soil nutrient status among the four agro-ecosystems and the significant effect that agro-ecosystem had on all soil nutrients. Examination of predictive models at the agro-ecosystem scale resulted in slightly greater success. Tillage could explain 42% of the variability of EOC in the forest-Guinea savannah transition agro-ecosystem and cropping explained 45% of the variability in EOC in the Guinea savannah. As the experiment runs for its full term (5 years) it is possible that tillage and cropping may be more successful in predicting soil nutrient status after a few more years of tillage and cropping,

# 3. EFFECT OF APPLYING TRIPLE SUPER PHOSPHATE, UREA AND COMPOST ON EXTRACTABLE SOIL NUTRIENTS

## 3.1 Introduction

It is well known that soil fertility is affected by many factors including the age and origin of soils, leaching, soil erosion, length of fallow period and how intensely fields have been cropped. Research in West Africa has shown that various combinations of these factors have resulted in low concentrations of soil organic matter (SOM) and limited the availability of needed crop nutrients, particularly phosphorus and nitrogen (Schlecht et al., 2006). Noting that three of the four sites used in this experiment are Lixisols, the predominance of 1:1 clays and low cation exchange capacities means that the reliance on SOM for both the retention and supply of plant available nutrients is increased (Fonte et al., 2009). This is in part due to Lixisols being associated with low fertility, expressed through low organic matter and total nitrogen, low cation exchange capacity and limited phosphorus (Bationo et al., 1991). In order to address these issues, the application of crop residues and compost has been promoted to increase cation retention in soils (Sanchez et al., 1989). Furthermore, it has been shown that in soils with low activity clays, soil organic matter does play a key role in alleviating soil degradation (Ross, 1993).

To date, research from around West Africa, and in particular Burkina Faso, has shown that the application of compost can improve soil properties and crop productivity in low input agricultural systems (Bationo et al., 1991, Ouedraogo et al., 2001).

Unsurprisingly, the application of mineral fertilizers has also been shown to assist in maintaining high crop productivity and reducing the effect of nutrient removal by crops (Giller et al., 1997). However, across much of Africa, and particularly in Ghana, the use of mineral fertilizer has been limited to cash crops (Sanabria et al., 2013). Although the fertilizer market of Ghana is the fourth largest in the West African region, the average nutrient fertilizer application rate in 2009 was estimated at 13.4 kg $ha^{-1}$ and primarily aimed at export crops (Fuentes et al., 2012). Nevertheless, across West Africa, the application of fertilizer has been shown to improve maize yields by 149% over an average of 4 years, while the additional application of lime and manure increased yields by 184%  (Mokwunye et al., 1996). Although mineral fertilizer use is still low and understanding that organic sources alone are not sufficient to replace nutrients lost or removed from the soils, West Africa needs to create an integrated soil fertility management system (Bationo et al., 2006).

With this in mind, along with prior research in West Africa, it was hypothesized that the application of mineral fertilizer will increase extractable soil nutrient concentrations compared to compost but will reduce extractable organic carbon (EOC) concentrations due to the lack of organic matter.

## 3.2 Materials and methods

### 3.2.1 Site description

Fertilization treatments were established in four agro-ecosystems in Ghana, W. Africa in 2011. The agro-ecosystems were 1) coastal savannah, 2) forest, 3) forest-

Guinea savannah transition and 4) Guinea savannah. The coastal savannah agro-ecosystem was situated in the Ga West district and Pokuase community. The soil was classified using the (World Reference Base for soil resources (WRB**)** 2006) as a Haplic Lixisol formed on granite with a loamy-sand texture to 60 cm. The forest agro-ecosystem was in the Amansie West district within the Ahwerewa community. The soil was classified as a Leptic Lixisol formed on phyllite with a silty-loam texture to 60 cm. The transition ecosystem was a forest- Guinea savannah transition situated in the Ejura-Sekodumase district within the Ejura-Adiembra community. The soil was classified as Leptic Lixisol formed on sandstone with a loamy sand texture to 30 cm. The Guinea savannah agro-ecosystem was in the Tolon-Kumbungu district within the Kumbungu-Kuko community. The soil was classified as a Pisolithic Plinthosol formed on shalestone with a silty loam texture to 60 cm (Davies et al. 2014).

Mean annual rainfall differed among the four agro-ecosystems. Mean annual rainfall for the four agro-ecosystems ranged from 1500 mm in the forest agro-ecosystem to 800 mm in the coastal savannah. Mean annual rainfall in the guinea savannah and forest-guinea savannah transition was 1100 and 1300 mm respectively. (Davies et al. 2014). Rainfall distribution over the study period varied among the agro-ecosystems studied (Chapter II).

### 3.2.2 Experimental Design

In each agro-ecosystem, a split plot design was implemented to test the effects of applying mineral phosphorus (Triple Super Phosphate), mineral nitrogen (Urea), compost (Asasse Nufuso) and phosphorus x nitrogen and phosphorus x compost interactions. The main plots were either (1) 0 kg P $ha^{-1}$, (2) 20 kg P $ha^{-1}$ or (3) 40 kg P $ha^{-1}$. The sub-plots were either: (1) 0 kg N $ha^{-1}$, (2) 70 kg N $ha^{-1}$, (3) 140 kg N $ha^{-1}$, (4) 0 kg Compost $ha^{-1}$ (5) 3000 kg Compost $ha^{-1}$ or (6) 6000 kg Compost $ha^{-1}$.

The test crop for the experiment was maize (*Zea mays)* as it is the cereal grown across all four agro-eco regions. Each plot was 5 m x 5 m with crop row spacing's for maize planted at 80 x 40 cm with 2 seeds per hill. All fertilizers were point applied, while the compost was broadcast across each plot. The compost used was Asaase Nufusuo (*"Earth's Breast milk"),* which is made from Cocoa (*Theobroma cacao*) husk. Its chemical analysis is 3.2% N, 3.2% $P_2O_5$ and 1.3% $K_2O$, 48% OM, 4.5% CaO and 0.2% MgO; while its nutrient content is 192 kg $ha^{-1}$ N, 192 kg $ha^{-1}$ $P_2O_5$, 78 kg $ha^{-1}$ $K_2O$, 2880 kg $ha^{-1}$ organic matter, 270 kg $ha^{-1}$ CaO and 120 kg $ha^{-1}$ MgO.

### 3.2.3 Soil sampling and processing

Soils were sampled in December 2012, two years after treatments commenced, using a 2 cm diameter soil probe to a depth of 15 cm. Due to the dependence on human labor and the use of hand held hoes as the main tilling tool, soils in Ghana tend not to be tilled deeper than approximately 15cm. Since each plot was 5 m x 5 m with 5-6 rows of planted crops, three soil cores were taken across the central row and bulked on site. Soils were air-dried and shipped to Texas A&M University for analysis.

Larger soil peds were gently broken using a mortar and pestle prior to sieving to <2 mm. Soil samples (3.5 g) were dissolved in 35 g of 0.1 M HCl (1:10 soil:HCl ratio) and shaken for two hours at 500 rpm on a rotary shaker. Samples were then centrifuged for 15 minutes at 19,974 g-force and filtered using a Whatman GF/F filter (nominal pore size 0.7 μm) to remove floating pieces of OM. Soil extracts were analyzed immediately after extraction for extractable organic C (EOC), total extractable N (TEN), $NH_4$-N, $NO_3$-N, and cations ($Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$). Extractable organic nitrogen (EON) was calculated by deducting $NO_3$-N plus $NH_4$-N from TEN.

To measure extractable P, the Bray 1 method was used (Bray et al, 1945). Soil samples (3 g) were dissolved in 21 g Bray 1 solution (1:7 Soil:Bray 1 ratio) and shaken vigorously by hand for 1 minute. Samples were then centrifuged for 5 minutes at 2,809 g-force and 25˚ C and filtered with Whatman GF/F filters (nominal pore size 0.7 μm). Soil extracts were analyzed immediately after extraction for $PO_4$-P

### 3.2.4 Chemical analyses

Extractable organic carbon (EOC) and total extractable nitrogen (TEN) were measured using a high temperature Pt-catalyzed combustion with a Shimadzu TOC-VCSH and Shimadzu total measuring unit TNM-1 (Shimadzu Corp. Houston, TX, USA). EOC was measured as non-purgeable carbon, which entails acidifying the sample (250 μL 2 M HCl) and sparging for 4 min with C-free air. $NH_4$-N was analyzed using the phenate hypochlorite method with Na nitroprusside enhancement (USEPA method 350.1) and $NO_3$-N was analyzed using Cd-Cu reduction (USEPA method 353.3). $PO_4$-P was analyzed using the ascorbic acid, molybdate blue method (APHA 1992). All colorimetric methods were performed with a Westco Scientific Smartchem Discrete

Analyzer (Westco Scientific Instruments Inc. Brookfield, CT, USA). Cations, $Na^{+}$, $K^{+}$, $Mg^{2+}$ and $Ca^{2+}$ were quantified by ion chromatography using an Ionpac CS12A analytical and Ionpac CG12A guard column for separation and 20mM methanosulfonic acid as eluent at a flowrate of 1 mL $min^{-1}$ and injection volume of 25 µL (DIONEX ICS 1000, DIONEX Corp. Sunnyvale, CA, USA). Sample replicates, blanks, NIST (National Institute of Standards and Technology) traceable and check standards were run every 12th sample to monitor instrument precision and co-efficient of variance among replicate samples.

### 3.2.5 Statistical analyses

Prior to analyses, data was checked for normal distribution and outliers were removed if non-normal distribution was evident. Univariate analysis of variance was used to examine the effect of agro-ecosystem, phosphorus application and N applications (urea and compost) and their interactions on soil nutrient status across the four agro-ecosystems in Ghana. Here agro-ecosystem, P treatment and N treatment were fixed factors and soil nutrients dependent variables. Univariate analysis of variance was also used to examine effects of phosphorus application and nitrogen application within individual agro-ecosystems. Two-sample, 1-tailed t-tests ($\alpha < 0.05$) were used to examine significant differences resulting from phosphorus and nitrogen treatments within each agro-ecosystem. Significant effects (univariate analysis of variance) were determined when $p < 0.10$ while differences (2 sample, 1-tail t-tests) were determined when $p < 0.05$. To determine if predictive models could be constructed to explain the percent variance in extractable soil nutrients a backward, stepwise, multiple regression analysis was performed for a) the whole dataset and b) individual agro-ecosystems. Pearson bivariate correlation analysis was used to examine correlations among nutrients extracted with 0.1 M HCl on the full dataset and on individual agro-ecosystems.

## 3.3 Results

### 3.3.1 Baseline soil nutrient status

Composite soil samples were collected by Dr. Kofi Boa prior to planting and initiation of the tillage treatments (*Dr. Kofi Boa, personal communication*). Analyses of these soils indicated that the soils in the coastal savannah and forest agro-ecosystems were moderately to slightly acidic across three depths (0-10, 10-30 and 30-50 cm), with pH ranging from 5.9 – 6.3 in the coastal savannah and 5.6 – 6.5 in the forest agro-ecosystems. Soils in the forest-guinea savannah transition site were very acidic (pH 4.3 - 5.0), and those in the guinea savanna site were acidic (pH 5.1 – 5.6) (*Dr. Kofi Boa, personal communication*).

Baseline soil C:N ratios ranged from 10.0 to 5.0 in the coastal savannah indicating a larger soil pool of N at 30-60 cm depth compared to 0-10 cm depth. In the forest soil, C:N ratio ranged from 12.0 to 10.0 illustrating a steady C:N ratio with depth. The transition zone had a soil C:N ratio of 11.7 to 14.0 and the guinea savannah a C:N ratio of 16.7 to 20.0 (*Dr. Kofi Boa, personal communication*).

### 3.3.2 Univariate analysis of variance

Using P and N treatments and agro-ecosystem as fixed factors type, univariate analysis of variance was performed across all the Ghanaian agro-ecosystems to determine the effect of P and N treatments and agro-ecosystem on soil nutrients. Significance was determined at $p < 0.10$. Agro-ecosystem had a significant effect on all soil nutrients and nutrient ratios (EOC:EON, EOC:TEN, EOC:$PO_4$-P and TEN:$PO_4$-P) with the exception of $Na^+$ and $K^+$. Phosphorus treatment had a significant effect on $PO_4$-P ($p = 0.02$), EOC:EON ratio ($p = 0.07$) and the TEN:$PO_4$-P ratio ($p = 0.06$). There was a significant interaction effect of agro-ecosystem type x P treatment on $NH_4$-N ($p = 0.02$), $Mg^{2+}$ ($p = 0.001$) and EOC:$PO_4$-P ratio ($p = 0.006$). N treatment had a significant effect on $NO_3$-N ($p = 0.03$), $PO_4$-P ($p = 0.03$), $Na^+$ ($p = 0.07$), $K^+$ ($p = 0.0004$), $Mg^{2+}$ ($p = 0.07$) and ratios EOC:TEN ($p = 0.07$), EOC:$PO_4$-P (0.02) and TEN:$PO_4$-P ($p = 0.03$). Significant interaction effects of agro-ecosystem type x N treatment on $NO_3$-N ($p = 0.07$), $Mg^{2+}$ ($p = 0.01$) and the TEN:$PO_4$-P ratio ($p = 0.006$) were observed. No significant interaction effects of P treatment x N treatment or P treatment x N treatment x agro-ecosystem type were observed (Table 16).

### 3.3.3 Effect of phosphorus and nitrogen amendments on soil nutrients in the coastal savannah

Univariate analysis of variance in the coastal savannah agro-ecosystem found no significant effect of P amendment on any of the extractable nutrients. There was a significant effect of N amendment on extractable $NO_3$-N ($p = 0.01$), EOC ($p = 0.08$) and

$K^+$ ($p = 0.03$). No significant interactions of P and N amendments on extractable nutrients were observed (Table 17).

Concentrations of extractable nutrients in the coastal savannah ranged from 8.3±3.1 to 25.3±17.4 for mg $NO_3$-N $kg^{-1}$, $NH_4$-N concentrations ranged from 6.2±1.9 to 12.3±7.8 mg $kg^{-1}$ and EON concentrations ranged from 0.0±0.0 to 1.9±3.3 mg $kg^{-1}$. $PO_4$-P concentrations ranged from 13.6±6.3 to 68.8±97.3 mg $kg^{-1}$ and EOC concentrations ranged from 43.4±12.9 to 116.3±86.8 mg $kg^{-1}$. Cation concentrations ranged from 25.2±12.7 to 67.9±46.6 mg $Na^+$ $kg^{-1}$ from 75.1±11.3 to 269.2±234.4 mg $K^+$ $kg^{-1}$, from 64.2±18.2 to 184.7±176.4 mg $Mg^{2+}$ $kg^{-1}$ and from 451.4±147.4 to 1057.2±963.1 mg $Ca^{2+}$ $kg^{-1}$ (Table 18).

Table 16. Univariate analysis of variance for the four agro-ecosystems in Ghana. EOC= Extractable Organic C, EON=Extractable Organic N. *Significant at $p < 0.10$ and **Significant at < 0.05. n = 216

| | | P | N | Zone | P x N | P x Zone | N x Zone | P x N x Zone | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| $NO_3$-N | F | 0.15 | 6.28 | 53.33 | 1.69 | 1.13 | 1.97 | 1.14 | 0.66 |
| | *p* | *0.86* | ***0.00**** | ***0.00**** | ***0.09**** | *0.35* | ***0.02**** | *0.30* | |
| $NH_4$-N | F | 0.33 | 0.11 | 9.58 | 0.49 | 1.25 | 0.32 | 0.45 | 0.30 |
| | *p* | *0.72* | *0.99* | ***0.00**** | *0.89* | *0.28* | *0.99* | *0.99* | |
| $PO_4$-P | F | 5.49 | 2.71 | 10.66 | 1.22 | 0.72 | 0.77 | 0.71 | 0.43 |
| | *p* | ***0.01**** | ***0.02**** | ***0.00**** | *0.29* | *0.63* | *0.71* | *0.87* | |
| EOC | F | 1.99 | 1.49 | 46.09 | 0.82 | 0.94 | 1.15 | 0.97 | 0.59 |
| | *p* | *0.14* | *0.20* | ***0.00**** | *0.61* | *0.47* | *0.32* | *0.51* | |
| EON | F | 2.63 | 1.45 | 31.43 | 1.45 | 1.23 | 1.23 | 1.21 | 0.56 |
| | *p* | ***0.08**** | *0.21* | ***0.00**** | *0.16* | *0.30* | *0.26* | *0.23* | |
| $Na^+$ | F | 0.49 | 1.20 | 5.93 | 0.58 | 0.72 | 0.41 | 1.22 | 0.36 |
| | *p* | *0.61* | *0.31* | ***0.00**** | *0.83* | *0.63* | *0.97* | *0.22* | |
| $K^+$ | F | 0.10 | 16.50 | 44.57 | 0.66 | 0.35 | 0.86 | 1.01 | 0.65 |
| | *p* | *0.90* | ***0.00**** | ***0.00**** | *0.76* | *0.91* | *0.60* | *0.46* | |
| $Mg^{2+}$ | F | 1.67 | 2.89 | 571.17 | 0.52 | 2.01 | 1.17 | 0.44 | 0.93 |
| | *p* | *0.19* | ***0.02**** | ***0.00**** | *0.87* | ***0.07**** | *0.30* | *0.99* | |
| $Ca^{2+}$ | F | 2.64 | 1.17 | 164.18 | 1.15 | 1.01 | 0.97 | 0.84 | 0.80 |
| | *p* | ***0.07**** | *0.33* | ***0.00**** | *0.33* | *0.42* | *0.49* | *0.71* | |

Table 17. Results of univariate analysis of variance in the coastal savannah agro-ecosystem. EOC= Extractable Organic C. *Significant at $p < 0.10$ and **Significant at $< 0.05$. $n = 54$

| | $NO_3$-N | | EOC | | $K^+$ | |
|---|---|---|---|---|---|---|
| Treatment | F Value | p value | F Value | p value | F Value | p value |
| P | 0.06 | 0.95 | 0.15 | 0.86 | 0.23 | 0.8 |
| N | 3.43 | **0.01**** | 2.14 | **0.08*** | 2.9 | **0.03**** |
| P x N | 1.64 | 0.14 | 1.24 | 0.3 | 1.08 | 0.4 |

3.3.3.1 0 kg $ha^{-1}$ Phosphate (P)

There were only two instances when application of 0 kg $ha^{-1}$ P had significantly higher concentrations of extractable soil nutrients in the coastal savannah agro-ecosystem of Ghana. The first was extractable soil $NO_3$-N within the 3000 kg $ha^{-1}$ compost posts, where 0 kg $ha^{-1}$ P had significantly more extractable $NO_3$-N than 20 kg $ha^{-1}$ of P (Table 18).

The second was for extractable $NH_4$-N, when plots receiving 0 kg $ha^{-1}$ P in combination with 70 kg $ha^{-1}$ N had significantly higher $NH_4$-N concentrations compared to plots receiving 40 kg $ha^{-1}$ P in combination with 70 kg $ha^{-1}$ N (Table 18).

### 3.3.3.2 20 kg ha$^{-1}$ Phospahte (P)

In the coastal savannah agro-ecosystem, the application of 20 kg ha$^{-1}$ P tended to result in significantly higher extractable $NH_4$-N, EOC, TEN and EON concentrations than plots receiving 0 P kg ha$^{-1}$. For extractable $NH_4$-N, in the plots receiving 3000 kg ha$^{-1}$ compost significantly lower concentrations of $NH_4$-N (8.0±0.2 mg kg$^{-1}$) were observed in 0 kg ha$^{-1}$ P compared to plots receiving 20 kg ha$^{-1}$ P (9.1±0.6 mg kg$^{-1}$). Although, in general, there was negligible extractable EON in the coastal savannah soils, in plots receiving 20 kg ha$^{-1}$ P and 3,000 kg ha$^{-1}$ of compost significantly higher extractable EON concentrations were observed compared to plots receiving 0 kg ha$^{-1}$ P and 3,000 kg ha$^{-1}$ of compost (Table 18).

While in the 70 kg ha$^{-1}$ N plots, 20 kg ha$^{-1}$ P had significantly more extractable EOC than the plots receiving 0 and 40 kg ha$^{-1}$ P.

### 3.3.3.3 40 kg ha$^{-1}$ Phosphate (P)

The application of 40 kg ha$^{-1}$ P tended to result in significantly more extractable nutrients than the application of 0 kg ha$^{-1}$ P. For extractable $NO_3$-N, within the 0 kg ha$^{-1}$ compost plots, 40 kg ha$^{-1}$ P had significantly more extractable $NO_3$-N than 0 kg ha$^{-1}$ P (Table 18).

For plots receiving 140 kg ha$^{-1}$ N plots with 40 kg ha$^{-1}$ P, significantly higher extractable $K^+$ (120.3±27.2 mg kg$^{-1}$) was observed when comparing plots receiving 140 kg ha$^{-1}$ N and 0 kg ha$^{-1}$ of P (75.1±11.3 mg kg$^{-1}$).

### 3.3.3.4 0 kg ha$^{-1}$ N

Overall, the application of 0 kg ha$^{-1}$ N often did not have much of a significant effect on extractable soil nutrients in the coastal savannah agro-ecosystem. However, within plots receiving 20 kg ha$^{-1}$ P plots, 0 kg ha$^{-1}$ N significantly higher extractable $NH_4$-N compared to plots receiving 140 kg ha$^{-1}$ N and 0 and 6000 kg ha$^{-1}$ compost. However, in the 40 Kg ha$^{-1}$ P plots, 0 kg ha$^{-1}$ N had significantly more $NH_4$-N than 70 kg ha$^{-1}$ N.

### 3.3.3.5 70 kg ha$^{-1}$ N

In the coastal savannah zone, the application of 70 kg ha$^{-1}$ did not have any significant influence on extractable soil nutrients after two years of application

### 3.3.3.6 140 kg ha$^{-1}$ N

In the plots receiving 0 kg ha$^{-1}$ P with 140 kg ha$^{-1}$ of N, significantly higher extractable $NO_3$-N was observed when compared to plots receiving 0 kg ha$^{-1}$ P and 0 kg ha$^{-1}$ of compost (Table 18). In the 40 kg ha$^{-1}$ plots, the application of 140 kg ha$^{-1}$ N had significantly more $Na^+$ than 70 kg ha$^{-1}$ N (Table 18).

### 3.3.3.7 0 kg ha$^{-1}$ Compost

The application of 0 kg ha$^{-1}$ compost also did not tend to have much effect on extractable soil nutrients after two years of treatments. However, significantly higher concentrations of $K^+$ where found in plots receiving 0 kg ha$^{-1}$ P plots with 0 kg ha$^{-1}$ compost compared to plots receiving 0 kg ha$^{-1}$ P with 140 kg ha$^{-1}$ N (Table 18). Also, in the 40 kg ha$^{-1}$ plots, the application of 0 kg ha$^{-1}$ resulted in more extractable $NH_4$-N than 70 kg ha$^{-1}$ N.

### 3.3.3.8 3000 kg ha$^{-1}$ Compost

In the coastal savannah, the application of 3000 kg ha$^{-1}$ compost was found to have many significant effects on extractable $NO_3$-N, $NO_4$-N, TEN, EON and $K^+$. For extractable $NO_3$-N, plots receiving the 0 kg ha$^{-1}$ P with 3000 kg ha$^{-1}$ of compost, significantly higher extractable $NO_3$-N compared to 70 kg ha$^{-1}$ N and 0 kg ha$^{-1}$ compost (Table 18). For extractable $NH_4$-N, in plots receiving 20 kg ha$^{-1}$ P with 3000 kg ha$^{-1}$ significantly higher $NH_4$-N was observed when compared to plots receiving 20 kg ha$^{-1}$ P and 140 kg ha$^{-1}$ N, 0 kg ha$^{-1}$ compost and 0 and 6000 kg ha$^{-1}$ compost (Table 18). For extractable soil EON, there was only a significance difference in the plots receiving 20 kg ha$^{-1}$ P plots with 3000 kg ha$^{-1}$ compost which had significantly higher EON than plots receiving 20 kg ha$^{-1}$ P in combination with 0,70, 140 kg ha$^{-1}$ N or 6000 kg ha$^{-1}$ compost.

In the plots receiving 20 kg ha$^{-1}$ P in combination with 3000 kg ha$^{-1}$ compost, significantly higher extractable $K^+$ concentrations were observed when comparing to plots receiving 20 kg ha$^{-1}$ P and 0 kg ha$^{-1}$ compost (Table 18).

Table 18. Soil nutrients in the Coastal Savannah agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (abc) within each Phosphorus group shows significant effect of Nitrogen/Compost applications at $p<0.05$. Differences in superscript letters (xyz) within Nitrogen/Compost groups shows a significant effect of Phosphorus application at $p<0.05$[5]

| P<br>kg ha$^{-1}$ | N/Compost<br>kg ha$^{-1}$ | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN<br>mg kg$^{-1}$ | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 8.3±3.1 | 8.2±1.1 | 14.5±7.2 | 46.3±9.6 | 15.4±5.4 | 0.1±0.2 | 44.2±42.9 | 92.4±38.5 | 67.7±26.1 | 451.4±147.4 |
| 0 | 70 | $^{ab}$9.0±1.8 | $^{y}$7.9±0.7 | 15.4±6.4 | $^{xa}$47.0±7.3 | $^{xa}$13.6±1.8 | 0.0±0.0 | 32.7±13.5 | 96.8±21.7 | 85.1±19.6 | 555.3±84.7 |
| 0 | 140 | $^{bc}$10.8±1.1 | 7.1±1.1 | 13.6±6.3 | 46.2±10.0 | $^{a}$15.3±0.9 | 0.0±0.0 | 38.6±3.5 | $^{xa}$75.1±11.3 | 73.8±21.8 | 520.3±156.1 |
| 0 | 0 | $^{xa}$8.9±0.2 | 7.7±0.5 | 17.7±11.9 | $^{a}$46.4±7.5 | $^{a}$14.9±0.9 | 0.0±0.0 | 34.9±9.3 | $^{b}$98.2±11.3 | 78.0±17.2 | 583.6±94.1 |
| 0 | 3000 | $^{yc}$11.3±0.3 | $^{x}$8.0±0.2 | 21.2±4.0 | $^{b}$58.1±5.6 | $^{b}$17.7±1.5 | $^{x}$0.0±0.0 | 36.9±11.1 | $^{b}$102.2±19.2 | 90.0±50.8 | 535.2±280.5 |
| 0 | 6000 | 25.3±17.4 | 12.3±7.8 | 33.2±19.4 | 116.3±86.8 | 37.1±24.6 | 0.4±0.8 | 50.9±16.5 | 269.2±234.4 | 184.7±176.4 | 1057.2±963.1 |
| 20 | 0 | 11.7±4.9 | $^{b}$9.1±1.1 | 22.7±5.2 | $^{a}$54.2±4.9 | 18.3±6.1 | $^{a}$0.0±0.0 | 28.8±12.0 | $^{ab}$104.2±11.0 | $^{a}$84.6±8.2 | 534.5±39.2 |
| 20 | 70 | 18.7±8.4 | 8.1±1.4 | $^{a}$19.3±6.9 | $^{y}$60.0±5.1 | $^{y}$24.6±8.6 | $^{a}$0.0±0.0 | 30.9±8.3 | $^{ab}$95.2±21.4 | $^{a}$66.2±20.0 | 497.4±125.2 |
| 20 | 140 | $^{a}$10.6±1.9 | $^{a}$6.9±0.5 | 21.6±13.2 | 55.2±11.1 | 15.3±1.7 | $^{a}$0.0±0.0 | 50.5±28.9 | $^{ab}$98.9±24.8 | $^{a}$65.1±13.2 | 482.7±99.3 |
| 20 | 0 | $^{a}$8.9±3.4 | $^{a}$6.2±1.9 | $^{a}$17.0±5.4 | 62.4±30.7 | 14.5±3.0 | 1.4±2.4 | 67.9±46.6 | $^{a}$94.1±4.7 | $^{a}$69.5±16.5 | 480.3±142.1 |
| 20 | 3000 | $^{xa}$8.8±1.2 | $^{yb}$9.1±0.6 | 24.3±12.7 | 52.7±17.1 | 17.0±4.4 | $^{yb}$0.5±0.4 | 47.3±32.2 | $^{bc}$124.8±20.5 | $^{a}$72.1±17.8 | 506.4±176.2 |
| 20 | 6000 | $^{b}$14.9±3.0 | $^{a}$7.0±0.6 | $^{b}$37.8±13.4 | $^{b}$64.6±6.3 | 19.9±4.3 | $^{a}$0.0±0.0 | 58.1±29.9 | $^{c}$143.9±14.2 | $^{b}$100.9±4.2 | 623.3±176.4 |
| 40 | 0 | $^{a}$9.6±1.3 | $^{b}$8.1±1.2 | 43.7±36.3 | 43.4±12.9 | $^{a}$15.0±2.4 | 0.3±0.5 | 34.8±10.9 | $^{a}$93.0±18.8 | $^{a}$64.2±18.2 | 502.0±140.8 |
| 40 | 70 | 14.3±4.4 | $^{xa}$6.2±0.9 | 35.0±27.6 | $^{x}$49.1±4.7 | 16.8±3.1 | 0.0±0.0 | $^{a}$25.2±12.7 | $^{a}$100.8±15.3 | 90.3±8.1 | 606.6±49.8 |
| 40 | 140 | 15.8±6.1 | 7.0±0.7 | 20.4±5.2 | 55.9±3.8 | 20.1±4.8 | 0.0±0.0 | $^{b}$54.1±19.3 | $^{y}$120.3±27.2 | 92.2±22.7 | 586.1±127.2 |
| 40 | 0 | $^{ya}$11.0±1.6 | $^{b}$7.6±2.1 | 35.2±32.9 | 69.4±24.9 | 18.8±4.2 | 1.9±3.3 | 39.2±8.4 | 100.5±29.0 | 91.8±20.1 | 585.9±192.2 |
| 40 | 3000 | 11.7±2.7 | 7.3±0.5 | 68.8±97.3 | 55.8±9.6 | 16.6±3.3 | $^{x}$0.0±0.0 | 56.4±28.0 | 123.3±34.0 | 95.1±17.2 | 619.9±156.2 |
| 40 | 6000 | $^{b}$14.4±1.5 | 7.3±1.1 | 38.4±16.9 | 60.8±11.4 | $^{b}$19.5±2.3 | 0.0±0.0 | 46.1±21.2 | $^{b}$131.1±19.8 | $^{b}$105.6±18.7 | 607.7±105.0 |

[5] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

3.3.3.9 6000 kg $ha^{-1}$ Compost

The application of 6000 kg $ha^{-1}$ compost also had an effect on extractable soil nutrients after two years of treatments. For extractable soil $NO_3$-N plots receiving 20 kg $ha^{-1}$ P in combination with 6000 kg $ha^{-1}$ compost had significantly higher extractable $NO_3$-N concentrations compared to 140 kg $ha^{-1}$ N and 0 and 3000 kg $ha^{-1}$ compost (Table 18). However, in the plots receiving 40 kg $ha^{-1}$ P, 6000 kg $ha^{-1}$ had significantly more extractable $NO_3$-N than 0 kg $ha^{-1}$ N and 0 kg $ha^{-1}$ Compost. For extractable $PO_4$-P, the application of 6000 kg $ha^{-1}$ compost in the 20 kg $ha^{-1}$ P main plots resulted in significantly higher concentrations of $PO_4$-P (37.8±13.4 mg $kg^{-1}$) when compared to plots receiving 20 kg $ha^{-1}$ P with 0 kg $ha^{-1}$ compost (17.0±5.4 mg $kg^{-1}$) or 70 kg $ha^{-1}$ N (19.3±6.9 mg $kg^{-1}$). For extractable $Mg^{2+}$, in the 20 kg $ha^{-1}$ P plots, the application of 6000 kg $ha^{-1}$ compost led to significantly more extractable $Mg^{2+}$ than all other N/compost treatments. However, in the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable $Mg^{2+}$ than 0 kg $ha^{-1}$ N. However, for extractable $K^+$, 6000 kg $ha^{-1}$ compost had significantly more than all other treatments except 3000 kg $ha^{-1}$ compost in the 20 kg $ha^{-1}$ P plots, while in the 40 kg $ha^{-1}$ plots, 6000 kg $ha^{-1}$ compost had more extractable $K^+$ than 0 and 70 kg $ha^{-1}$ N.

### 3.3.4 Effect of phosphorus and nitrogen amendments on soil nutrients in the forest agro-ecosystem

Univariate analysis of variance found significant effects of P application and N application on some soil nutrients in the forest agro-ecosystem. P application had a significant effect on extractable $PO_4$-P ($p = 0.03$), $Mg^{2+}$ ($p = 0.03$) and $NH_4$-N ($p = 0.08$). Application of N to soil had a significant effect on extractable $NH_4$-N ($p = 0.04$), $PO_4$-P ($p = 0.05$) and $K^+$ ($p = 0.0001$). There was no significant interaction effect of P and N amendments in the forest agro-ecosystem (Table 19).

Concentrations of extractable nutrients varied in the forest agro-ecosystem. $NO_3$-N concentrations ranged from 8.2±3.2 to 13.9±2.4 mg $kg^{-1}$, $NH_4$-N concentrations ranged from 4.1±0.6 to 46.1±70.5 mg $kg^{-1}$ and EON concentrations ranged from 0.5±0.8 to 19.4±24.1mg $kg^{-1}$. $PO_4$-P concentrations ranged from 1.4±0.5 to 33.7±31.3 mg $kg^{-1}$ and EOC concentrations ranged from 80.8±9.2 to 150.2±42.9 mg $kg^{-1}$. Cation concentrations ranged from 39.1±8.8 to 76.6±20.6 mg $Na^+$ $kg^{-1}$ from 39.6±7.2 to 90.4±27.5 mg $K^+$ $kg^{-1}$, from 274.7±138.2 to 354.8±31.1 mg $Mg^{2+}$ $kg^{-1}$ and from 1010.5±439.3 to 1796.7±571.8 mg $Ca^{2+}$ $kg^{-1}$ (Table 20).

Table 19. Results of univariate analysis of variance in the forest agro-ecosystem. *Significant at $p < 0.10$ and **Significant at < 0.05. n = 54

| Treatment | $NH_4$-N | | $PO_4$-P | | $K^+$ | | $Mg^{2+}$ | |
|---|---|---|---|---|---|---|---|---|
| | F Value | p value | F Value | p value | F Value | p value | F Value | p value |
| P | 2.76 | **0.08*** | 4.07 | **0.03**** | 0.09 | 0.91 | 3.24 | **0.05*** |
| N | 2.69 | **0.04**** | 2.50 | 0.05* | 6.19 | **0.00**** | 1.20 | 0.33 |
| P x N | 0.73 | 0.69 | 1.76 | 0.11 | 0.36 | 0.95 | 0.19 | 1.00 |

### 3.3.4.1 0 kg ha$^{-1}$ Phosphate (P)

The application of 0 kg ha$^{-1}$ P had some significant effects on $Na^+$ and $Mg^{2+}$ in the forest agro-ecosystem. Plots receiving 0 kg ha$^{-1}$ P in combination with 6000 kg ha$^{-1}$ compost resulted in significantly higher extractable $Na^+$ than plots receiving 20 kg ha$^{-1}$ P with 6000 kg ha$^{-1}$ compost (Table 20).

Concentrations of extractable $Mg^{2+}$ were significantly higher in plots receiving 0 kg ha$^{-1}$ P in combination 0 kg ha$^{-1}$ N compared to plots receiving 40 kg ha$^{-1}$ P with 0 kg ha$^{-1}$ N (Table 20).

### 3.3.4.2 20 kg ha$^{-1}$ Phosphate (P)

The application of 20 kg ha$^{-1}$ P did have a significant effect on extractable soil $NH_4$-N, EOC, TEN, EON, $Na^+$ in the forest agro-ecosystem of Ghana. For extractable $NH_4$-N, in the plots receiving a combination of 20 kg ha$^{-1}$ P and 3000 kg ha$^{-1}$ compost, significantly higher $NH_4$-N concentrations were observed when comparing to plots receiving a combination of 40 kg $ha^{-1}$ P and 3000 kg $ha^{-1}$ compost (Table 20). For EON, in the plots receiving a combination of 20 kg $ha^{-1}$ P and 70 kg $ha^{-1}$ N, significantly higher EON concentrations were observed compared to plots receiving than 0 kg $ha^{-1}$ P 70 kg $ha^{-1}$ N (Table 20).

Application of 20 kg $ha^{-1}$ P with 70 kg $ha^{-1}$ N resulted in significantly higher concentrations of EOC (104.5±9.6 kg $ha^{-1}$) compared to plots receiving 0 kg $ha^{-1}$ P and 70 kg $ha^{-1}$ N (80.8±9.2 kg $ha^{-1}$). For extractable $Na^+$, the application of 20 kg $ha^{-1}$ P with 3000 kg $ha^{-1}$ compost had significantly more than 40 kg $ha^{-1}$ P with 3000 kg $ha^{-1}$ compost.

### 3.3.4.3 40 kg $ha^{-1}$ Phosphate (P)

Results for 40 kg $ha^{-1}$ P were similar to findings for 20 kg $ha^{-1}$ P. Significant differences were found for $NO_3$-N, TEN, $PO_4$-P, and $Ca^{2+}$ in the forest agro-ecosystem of Ghana.

For extractable $NO_3$-N, in the 6000 kg $ha^{-1}$ compost plots applied with 40 kg $ha^{-1}$ P had significantly higher extractable nitrate concentrations when compared to 6000 kg $ha^{-1}$ applied with 0 kg $ha^{-1}$ P.

Extractable $PO_4$-P concentrations were significantly higher in plots receiving 40 kg $ha^{-1}$ P with 140 kg kg $ha^{-1}$ N compared to plots receiving a combination of 0 kg $ha^{-1}$ P with 140 kg kg $ha^{-1}$ N (Table 20). For TEN, in plots receiving 70 kg $ha^{-1}$ N in combination with 40 kg $ha^{-1}$ P significantly higher concentrations of TEN were observed when compared to plots receiving 70 kg $ha^{-1}$ N with 0 kg $ha^{-1}$ P. In plots receiving 40 kg

$ha^{-1}$ P in combination with 3000 kg $ha^{-1}$ compost, soil extractable $Ca^{2+}$ concentrations were significantly higher when compared to plots receiving 3000 3000 kg $ha^{-1}$ compost with 0 or 20 kg $ha^{-1}$ P. (Table 20).

#### 3.3.4.4 0 kg $ha^{-1}$ N

The application of 0 kg $ha^{-1}$ N only had significance on extractable soil $Mg^{2+}$ in the forest agro-ecosystem of Ghana. Here in the plots receiving 0 kg $ha^{-1}$ P plots with 140 kg $ha^{-1}$ N significantly lower soil extractable soil $Mg^{2+}$ was observed compared to plots receiving 0 kg $ha^{-1}$ P with 0 kg $ha^{-1}$ N (Table 20).

#### 3.3.4.5 70 kg $ha^{-1}$ N

70 kg $ha^{-1}$ N applied with P had more effects compared to other N applications. Here the application of 70 kg $ha^{-1}$ N had a significant effect on extractable $NH_4$-N, EON, TEN and $Mg^{2+}$.

For extractable $NH_4$-N, within the 0 kg $ha^{-1}$ P plots, the application 0 kg $ha^{-1}$ N and 6000 kg $ha^{-1}$ compost led to significantly less extractable $NH_4$-N than 70 kg $ha^{-1}$ N in the 0 kg $ha^{-1}$ P plots (Table 20). However, in the 40 kg $ha^{-1}$ P plots, 70 kg $ha^{-1}$ N had significantly more TEN than 140 kg $ha^{-1}$ N (Table 20).

In the 20 kg $ha^{-1}$ P plots, 70 kg $ha^{-1}$ had significantly more EON than 6000 kg $ha^{-1}$ compost, as well as significantly more extractable $Mg^{2+}$ than 140 kg $ha^{-1}$ N.

3.3.4.6 140 kg $ha^{-1}$ N

140 kg $ha^{-1}$ N had significantly higher extractable soil $NH_4$-N concentrations compared to plots receiving than 6000 kg $ha^{-1}$ compost in the plots receiving 0 kg $ha^{-1}$ P (Table 20).

3.3.4.7 0 kg $ha^{-1}$ Compost

In the 40 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ compost (59.2±10.1 kg $ha^{-1}$) had significantly more extractable soil $Na^+$ than 3000 kg $ha^{-1}$ compost (39.1±8.8).

3.3.4.8 3000 kg $ha^{-1}$ Compost

In the forest agro-ecosystem, 3000 kg $ha^{-1}$ compost had a significant effect on $NO_3$-N, $PO_4$-P, EOC, EON $Na^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$. Extractable $NO_3$-N was significantly higher, in the plots receiving 20 kg $ha^{-1}$ P and 3000 kg $ha^{-1}$ compost, compared to plots receiving 20 kg $ha^{-1}$ P and 140 kg $ha^{-1}$ N or 0 kg $ha^{-1}$ compost (Table 20). For extractable $PO_4$-P, in the 40 kg $ha^{-1}$ P forest agro-ecosystem plots, 3000 kg $ha^{-1}$ compost had significantly more extractable soil P than 140 kg $ha^{-1}$ N (Table 20). For EON and EOC, within 40 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost had significantly more EOC than 140 kg $ha^{-1}$ N and 0 kg $ha^{-1}$ compost (Table 20). In the 20 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost had significantly more extractable soil Na+ than 0, 140 kg $ha^{-1}$ N and 6000 kg $ha^{-1}$ compost (Table 20). Staying within the 20 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost plots again had significantly more extractable soil K+ than all N treatments (Table 20). The trend continues in the 40 kg $ha^{-1}$ P plots where 3000 kg $ha^{-1}$ compost had significantly higher amounts of extractable K+ compared to 70 kg $ha^{-1}$ N and the 0 kg $ha^{-1}$ compost treatment (Table 20). However, for extractable $Ca^{2+}$, within the 40 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost had a significantly higher amount than 0 kg $ha^{-1}$ compost (Table 20). Lastly, in the 0 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost had significantly more for extractable $Mg^{2+}$than 140 kg $ha^{-1}$ N (Table 20).

3.3.4.9 6000 kg $ha^{-1}$ Compost

Similar to the coastal savannah agro-ecosystem, in the forest agro-ecosystem the application of 6000 kg $ha^{-1}$ of compost had a huge effect on extractable soil nutrients. In the forest agro-ecosystem 0 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ had significantly more extractable $NO_3$-N than 3000 kg $ha^{-1}$ compost. In the 20 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable $NO_3$-N than 0 kg $ha^{-1}$ compost (Table 20). Furthermore, in the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable $NO_3$-N than 140 kg $ha^{-1}$ N and 0 kg $ha^{-1}$ compost (Table 20). For EON, in the 0 kg $ha^{-1}$ P plots of the forest agro-ecosystem, 6000 kg $ha^{-1}$ compost had significantly more EON than 70 kg $ha^{-1}$ N (Table 20).

For extractable $PO_4$-P, within the 0 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost (5.8±2.4) had significantly more extractable $PO_4$-P than all other treatments except for 0 kg $ha^{-1}$ N (4.3±3.8). In the 20 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable soil $PO_4$-P than 70 and 140 kg $ha^{-1}$ N treatments (Table 20).

Table 20. Soil nutrients in the Forest agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (abc) within each Phosphorus group show significant effect of Nitrogen/Compost applications at $p<0.05$. Differences in superscript letters (xyz) within Nitrogen/Compost groups shows a significant effect of Phosphorus application at $p<0.05$.[6]

| P | N/Compost | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kg ha$^{-1}$ | kg ha$^{-1}$ | | | | | mg kg$^{-1}$ | | | | | |
| 0 | 0 | 9.1±4.6 | $^{ab}$4.8±0.4 | 4.3±3.8 | 89.1±9.3 | 15.4±3.0 | 1.7±1.8 | $^{a}$46.3±11.3 | 48.6±12.6 | $^{yb}$346.6±17.3 | 1313.5±192.7 |
| 0 | 70 | 8.7±3.8 | $^{c}$5.7±0.4 | $^{a}$1.4±0.5 | $^{x}$80.8±9.2 | $^{x}$14.6±3.7 | $^{xa}$0.5±0.8 | 60.5±30.6 | 46.5±13.5 | 335.5±51.1 | 1116.5±164.2 |
| 0 | 140 | 10.6±3.8 | $^{bc}$5.2±0.6 | $^{xa}$1.8±0.6 | 87.1±23.6 | 18.6±7.8 | 3.2±3.3 | $^{a}$43.6±11.6 | 50.5±6.8 | $^{a}$306.2±13.0 | 1183.7±137.2 |
| 0 | 0 | 9.2±1.5 | 46.1±70.5 | $^{a}$1.5±0.1 | 110.1±33.4 | 59.6±66.6 | 4.3±7.5 | 67.6±36.1 | 50.4±6.3 | 339.9±25.9 | 1131.0±148.9 |
| 0 | 3000 | $^{a}$9.4±0.9 | 5.4±1.3 | $^{a}$1.8±0.3 | 101.8±17.7 | 18.1±2.3 | 3.3±3.6 | 66.1±22.0 | 63.3±17.5 | $^{b}$339.9±24.3 | $^{x}$1171.6±199.4 |
| 0 | 6000 | $^{xb}$10.7±0.5 | $^{a}$4.1±0.6 | $^{b}$5.8±2.4 | 102.1±19.0 | 18.7±2.6 | $^{b}$3.9±2.1 | $^{yb}$76.6±20.6 | 79.1±25.1 | 333.0±31.1 | 1150.4±156.4 |
| 20 | 0 | 10.2±3.0 | 6.6±2.7 | 6.8±4.7 | 112.7±33.9 | 20.9±8.6 | 4.1±3.5 | $^{a}$42.4±5.3 | $^{a}$41.6±10.9 | 315.2±39.0 | 1226.3±281.7 |
| 20 | 70 | 10.9±2.0 | 8.2±2.9 | $^{a}$2.0±0.7 | $^{y}$104.5±9.6 | $^{y}$24.5±7.1 | $^{yb}$5.4±3.1 | 58.6±30.6 | $^{a}$41.1±9.0 | $^{b}$354.8±31.1 | 1218.7±231.7 |
| 20 | 140 | $^{ab}$8.9±0.7 | 6.3±0.9 | $^{a}$2.8±1.4 | 94.7±22.9 | 16.4±1.1 | 1.4±1.4 | $^{a}$38.0±8.7 | $^{a}$47.1±18.0 | $^{a}$301.1±29.0 | 1192.4±138.5 |
| 20 | 0 | $^{a}$8.8±0.5 | 5.9±1.8 | 33.7±31.3 | 112.1±19.4 | 20.8±5.3 | 6.2±5.9 | 62.6±37.4 | 61.5±22.3 | 328.5±38.3 | 1204.5±233.7 |
| 20 | 3000 | $^{c}$13.6±3.5 | $^{y}$6.4±0.7 | 18.4±22.0 | 101.9±18.7 | 22.8±6.8 | 2.8±2.7 | $^{yb}$51.4±3.6 | $^{b}$76.2±5.3 | 336.6±28.4 | $^{x}$1071.1±48.8 |
| 20 | 6000 | $^{bc}$13.0±3.5 | 5.3±0.9 | $^{b}$22.0±14.3 | 98.9±23.4 | 19.6±4.4 | $^{a}$1.3±1.4 | $^{xa}$40.7±7.0 | 87.8±39.2 | 333.1±23.0 | 1220.4±238.8 |
| 40 | 0 | 11.7±6.8 | 4.7±0.5 | 6.0±6.2 | 140.3±110.6 | 23.7±16.5 | 8.1±8.9 | 57.4±29.1 | 52.6±28.9 | $^{x}$295.9±30.0 | 1411.2±521.7 |
| 40 | 70 | 15.2±5.2 | 5.7±5.7 | 6.1±5.1 | 112.3±64.1 | $^{yb}$38.9±16.5 | 19.4±24.1 | 49.0±21.8 | $^{a}$40.1±1.9 | 316.0±36.1 | 1340.0±279.1 |
| 40 | 140 | $^{a}$9.3±1.1 | 4.7±1.4 | $^{ya}$3.7±0.6 | $^{a}$79.7±20.0 | $^{a}$15.6±5.3 | $^{a}$2.0±2.6 | 94.2±94.1 | 48.7±29.0 | 253.3±93.1 | 1062.2±295.8 |
| 40 | 0 | $^{a}$8.2±3.2 | 7.1±3.8 | $^{ab}$3.9±2.8 | $^{ab}$83.4±24.3 | $^{a}$16.7±7.8 | $^{a}$2.0±2.6 | $^{b}$59.2±10.1 | $^{a}$39.6±7.2 | 304.5±25.9 | $^{a}$1105.7±104.6 |
| 40 | 3000 | 12.4±4.0 | $^{x}$4.3±0.6 | $^{bc}$32.5±26.6 | $^{c}$150.2±42.9 | 25.8±9.4 | $^{b}$9.1±5.2 | $^{xa}$39.1±8.8 | $^{b}$78.1±26.2 | 309.2±23.4 | $^{yb}$1796.7±571.8 |
| 40 | 6000 | $^{yb}$13.9±2.4 | 4.6±0.4 | $^{c}$12.4±5.5 | $^{bc}$118.8±18.1 | 24.2±6.4 | 5.7±3.6 | 57.1±18.7 | $^{b}$90.4±27.5 | 274.7±138.2 | 1010.5±439.3 |

[6] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

However, in the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost (12.4±5.5) also had significantly more extractable $PO_4$-P than 140 kg $ha^{-1}$ N (3.7±0.6) and 0 kg $ha^{-1}$ compost (3.9±2.8).

6000 kg $ha^{-1}$ compost also had a significant effect on extractable EOC. Within the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more EOC than 140 kg $ha^{-1}$ N (Table 20).

6000 kg $ha^{-1}$ compost again had a significant effect on extractable soil $K^+$ in the forest agro-ecosystem. Within the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable $K^+$ than 70 kg $ha^{-1}$ N and 0 kg $ha^{-1}$ compost (Table 20).

### 3.3.5 Effect of phosphorus and nitrogen amendments on soil nutrients in the forest-guinea savannah transition

Univariate analysis of variance found significant effects of P amendments and N amendments on some soil nutrients in the forest-guinea savannah transition agro-ecosystem. P amendment had a significant effect on extractable $PO_4$-P ($p = 0.00$), EOC ($p = 0.00$) and $Ca^{2+}$ ($p = 0.05$). N amendment had a significant effect on extractable $PO_4$-P ($p = 0.07$), EOC ($p = 0.06$) and $K^+$ ($p = 0.00$). There was also a significant interaction effect between P and N amendments for $PO_4$-P ($p = 0.07$) in the forest-guinea savannah transition agro-ecosystem (Table 21).

Concentrations of extractable nutrients in the forest-guinea savannah ranged from 2.3±2.1 to 5.8±0.9 for mg $NO_3$-N $kg^{-1}$, $NH_4$-N concentrations ranged from 5.1±1.2 to 11.8±6.1 mg $kg^{-1}$ and EON concentrations ranged from 1.5±0.7 to 16.3±8.8 mg $kg^{-1}$.

$PO_4$-P concentrations ranged from 4.5±1.0 to 31.9±17.1 mg $kg^{-1}$ and EOC concentrations ranged from 51.3±1.2 to 82.5±15.0 mg $kg^{-1}$. Cation concentrations ranged from 27.9±2.7 to 56.3±33.2 mg $Na^{+}$ $kg^{-1}$ from 34.7±9.2 to 126.9±41.9 mg $K^{+}$ $kg^{-1}$, from 72.9±4.1 to 123.3±42.0 mg $Mg^{2+}$ $kg^{-1}$ and from 397.0±45.6 to 824.3±202.8 mg $Ca^{2+}$ $kg^{-1}$ (Table 22).

Table 21. Results of univariate analysis of variance in the forest –guinea savannah transition agro-ecosystem. EOC=Extractable Organic C. *Significant at $p < 0.10$ and **Significant at < 0.05. n = 54

| | $PO_4$-P | | EOC | | $K^{+}$ | | $Ca^{2+}$ | |
|---|---|---|---|---|---|---|---|---|
| Treatment | F Value | p value | F Value | p value | F Value | p value | F Value | p value |
| P | 7.91 | **0.00**** | 6.26 | **0.00**** | 0.64 | 0.53 | 3.26 | **0.05*** |
| N/Compost | 2.28 | **0.07*** | 2.39 | **0.06*** | 19.24 | **0.00**** | 0.91 | 0.48 |
| P x N/Compost | 1.93 | **0.07*** | 0.82 | 0.61 | 0.48 | 0.89 | 0.69 | 0.73 |

3.3.5.1 0 kg $ha^{-1}$ Phosphate (P)

In the forest-guinea savannah, 0 kg $ha^{-1}$ P had a significant effect on extractable soil $Na^{+}$. Within the 140 kg $ha^{-1}$ N and 0 kg $ha^{-1}$ compost plots, 0 kg $ha^{-1}$ P had significantly more than 40 kg $ha^{-1}$ P.

3.3.5.2 20 kg $ha^{-1}$ Phosphate (P)

The application of 20 kg $ha^{-1}$ P tended to have a significant effect against plots receiving 0 kg $ha^{-1}$ P. Overall, significant effects were found for TEN, EON, $PO_4$-P, EOC, $Na^+$ and $Ca^{2+}$.

For TEN, EOC, and EON, 20 kg $ha^{-1}$ P had significantly higher amounts than 0 kg $ha^{-1}$ P in the 140 kg $ha^{-1}$ N and 6000 kg $ha^{-1}$ compost plots (Table 22). 20 kg $ha^{-1}$ P also had significantly more extractable EOC than the 40 kg $ha^{-1}$ P in the 6000 kg $ha^{-1}$ compost plots (Table 22). However, for extractable $Na^{2+}$, in the 70 kg $ha^{-1}$ N plots, 20 kg $ha^{-1}$ P had significantly more than 40 kg $ha^{-1}$ P. Lastly, in the 6000 kg $ha^{-1}$ compost plots, 20 kg $ha^{-1}$ P had significantly more than 0 kg $ha^{-1}$ P.

3.3.5.3 40 kg $ha^{-1}$ Phosphate (P)

In the forest-guinea savannah transition zone, the application of 40 kg $ha^{-1}$ of P had significant results for $PO_4$-P, EOC and $Ca^{2+}$. For extractable $PO_4$-P, 40 kg $ha^{-1}$ P had significantly more extractable soil P than 0 kg $ha^{-1}$ P within the 0 kg $ha^{-1}$ N treatments (Table 22). When assessing EOC in the forest-guinea savannah transition agro-ecosystem, 40 kg $ha^{-1}$ P had significantly more extractable EOC than 0 kg $ha^{-1}$ P within the 6000 kg $ha^{-1}$ compost (Table 22). For extractable $Ca^{2+}$, 40 kg $ha^{-1}$ P had significantly more the 0 kg $ha^{-1}$ P within the 70 kg $ha^{-1}$ plots.

Table 22. Soil nutrients in the Forest-Guinea Savannah transition agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (abc) within each Phosphorus group shows significant effect of Nitrogen/Compost applications at $p<0.05$. Differences in superscript letters (xyz) within N/Compost groups shows a significant effect of Phosphorus application at $p<0.05$[7]

| P | N/Compost | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kg ha-1 | kg ha-1 | | | | | | mg kg$^{-1}$ | | | | |
| 0 | 0 | 2.3±2.1 | 5.7±0.8 | $^{x}$5.6±1.0 | 55.4±7.1 | $^{a}$11.9±5.8 | $^{a}$3.9±4.1 | 34.9±15.9 | $^{a}$40.6±12.6 | $^{a}$75.5±14.0 | 448.0±132.6 |
| 0 | 70 | 3.2±2.5 | 6.2±1.4 | $^{a}$4.8±0.7 | 51.5±10.8 | $^{a}$12.6±5.7 | $^{a}$3.2±3.5 | 35.7±20.9 | $^{a}$34.7±9.2 | $^{a}$72.9±4.1 | $^{xa}$397.0±45.6 |
| 0 | 140 | 5.7±2.3 | 5.8±0.3 | $^{a}$4.5±1.0 | $^{xa}$51.3±1.2 | $^{xa}$13.1±1.8 | $^{xa}$1.5±0.7 | $^{yb}$47.3±14.3 | $^{a}$49.0±13.8 | 96.1±21.8 | $^{b}$504.4±53.0 |
| 0 | 0 | 4.3±1.2 | 8.7±3.5 | 7.4±4.6 | $^{b}$65.7±8.3 | $^{b}$29.4±12.9 | $^{b}$16.3±8.8 | $^{yb}$34.8±3.4 | $^{a}$40.1±10.8 | $^{b}$98.4±10.7 | $^{b}$529.1±97.1 |
| 0 | 3000 | 3.2±2.6 | 5.7±0.6 | 13.6±9.0 | 57.1±13.1 | 12.1±6.8 | $^{a}$3.2±4.1 | 48.7±35.4 | $^{b}$83.9±24.6 | 92.4±16.4 | 558.9±137.9 |
| 0 | 6000 | 4.7±2.6 | 5.3±0.7 | $^{b}$10.8±4.5 | $^{xb}$58.3±1.7 | $^{xa}$12.0±4.7 | $^{xa}$1.9±1.7 | $^{a}$28.6±2.7 | $^{b}$97.7±9.6 | $^{b}$107.6±6.1 | $^{x}$525.0±145.6 |
| 20 | 0 | $^{a}$2.5±1.5 | 5.4±0.7 | 12.5±8.2 | $^{a}$57.0±6.0 | $^{a}$10.2±2.6 | $^{a}$2.3±1.5 | 27.9±2.7 | $^{a}$46.0±9.7 | 94.8±23.7 | 665.6±219.3 |
| 20 | 70 | 4.3±1.1 | 9.0±3.6 | $^{a}$8.0±3.3 | $^{ab}$61.1±10.1 | $^{b}$17.5±4.7 | 5.2±4.6 | $^{y}$29.8±9.0 | $^{a}$47.4±7.4 | 87.8±34.4 | $^{a}$494.4±115.3 |
| 20 | 140 | $^{b}$5.0±1.0 | 8.7±4.0 | $^{a}$8.8±3.9 | $^{ybc}$72.0±7.1 | $^{yb}$23.8±5.5 | $^{yb}$10.2±2.1 | 42.6±13.8 | $^{ab}$53.3±19.2 | 97.4±21.0 | 704.7±358.6 |
| 20 | 0 | 4.1±2.5 | 9.6±7.1 | $^{a}$7.1±1.3 | 67.2±12.8 | 22.7±11.1 | 9.0±6.0 | 34.2±8.3 | $^{a}$46.6±13.6 | 81.5±22.0 | $^{a}$494.6±82.6 |
| 20 | 3000 | 4.5±0.8 | 6.6±2.7 | $^{b}$17.2±5.0 | $^{bc}$70.2±6.0 | 22.3±15.6 | 11.2±12.3 | 34.3±14.2 | $^{bc}$84.9±25.3 | 100.1±29.7 | 565.7±124.3 |
| 20 | 6000 | $^{b}$5.8±0.9 | 11.8±6.1 | $^{b}$31.9±17.1 | $^{yc}$82.5±15.0 | $^{yb}$32.9±14.7 | $^{yb}$15.3±9.5 | 30.1±4.3 | $^{c}$103.9±27.9 | 106.9±18.0 | $^{yb}$824.3±202.8 |
| 40 | 0 | 3.2±2.2 | 5.1±1.2 | $^{y}$58.8±43.0 | 65.8±20.4 | 14.1±3.7 | 5.8±2.7 | 33.0±11.0 | $^{ab}$46.3±20.1 | 78.6±28.0 | 703.1±352.0 |
| 40 | 70 | 4.9±1.8 | 5.9±1.0 | 12.8±9.9 | 64.9±8.6 | 15.2±4.0 | 4.5±3.6 | $^{xb}$41.4±2.7 | $^{a}$40.5±9.2 | 100.4±26.3 | $^{y}$665.7±181.1 |
| 40 | 140 | 3.8±1.2 | 9.9±6.1 | 21.8±21.5 | 59.9±12.1 | 21.2±11.3 | 7.5±5.7 | $^{xa}$25.8±4.4 | $^{a}$39.5±11.5 | $^{a}$68.6±15.2 | 492.1±173.0 |
| 40 | 0 | 3.7±0.8 | 8.4±5.9 | 21.8±14.1 | 66.6±11.0 | 20.6±17.8 | 8.5±11.3 | $^{xa}$28.2±3.9 | $^{ab}$51.6±12.0 | $^{b}$108.1±13.6 | 746.3±204.1 |
| 40 | 3000 | 3.3±1.3 | 11.2±9.2 | 12.0±6.3 | 64.2±3.8 | 23.2±12.4 | 8.6±4.7 | $^{a}$28.9±7.2 | $^{bc}$80.4±27.1 | 88.3±28.1 | 575.5±280.4 |
| 40 | 6000 | 4.3±2.7 | 9.0±6.4 | 28.1±16.5 | $^{y}$81.4±19.4 | 22.1±10.9 | 8.8±6.7 | 56.3±33.2 | $^{c}$126.9±41.9 | $^{b}$123.3±42.0 | 798.6±392.7 |

[7] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

#### 3.3.5.4 0 kg $ha^{-1}$ N

In the forest-Guinea savannah region, 0 kg $ha^{-1}$ N did not have a significant effect on extractable soil nutrients.

#### 3.3.5.5 70 kg $ha^{-1}$ N

The application of 70 kg $ha^{-1}$ N also did not have much effect on soil nutrients in the forest-guinea savannah agro-ecosystem. In the 40 kg $ha^{-1}$ P treatments, 70 kg $ha^{-1}$ had significantly more extractable soil $Na^+$ than 140 kg $ha^{-1}$ N, 0 kg $ha^{-1}$ compost and 3000 kg $ha^{-1}$ compost (Table 22). While in the 20 kg $ha^{-1}$ P treatments, 70 kg $ha^{-1}$ N had significantly more extractable TEN than 0 kg $ha^{-1}$ N.

#### 3.3.5.6 140 kg $ha^{-1}$ N

Overall, the application of 140 kg $ha^{-1}$ N tended to have a significant impact when compared to the application of 0 kg $ha^{-1}$ N or compost. In the forest-guinea savannah agro-ecosystem, 140 kg $ha^{-1}$ was found significant for extractable soil $NO_3$-N, TEN, EON, EOC, $Na^+$ and $Ca^{2+}$.

Within the 20 kg $ha^{-1}$ P plots, 140 kg $ha^{-1}$ N (5.0±1.0) had significantly more extractable soil $NO_3$-N than 0 kg $ha^{-1}$ N (2.5±1.5). Also in the 20 kg $ha^{-1}$ P plots; 140 kg $ha^{-1}$ N (23.8±5.5) also had significantly more TEN than 0 kg $ha^{-1}$ N (10.2±2.6). For EON, 140 kg $ha^{-1}$ N had significantly more EON than 0 kg $ha^{-1}$ N within the 20 kg $ha^{-1}$ P plots (Table 22).

For EOC, in the 20 kg $ha^{-1}$ P plots, 140 kg $ha^{-1}$ N was also found to have significantly more EOC than 0 kg $ha^{-1}$ N treatments (Table 22). However, within 0 kg $ha^{-1}$ P plots, 140 kg $ha^{-1}$ N had significantly more extractable $Na^+$ than 6000 kg $ha^{-1}$ compost (Table 22). Lastly, in the 0 kg $ha^{-1}$ P plots, 140 kg $ha^{-1}$ N had significantly more extractable $Ca^{2+}$ than 70 kg $ha^{-1}$ N (Table 22).

### 3.3.5.7 0 kg $ha^{-1}$ Compost

Surprisingly, the application of 0 kg $ha^{-1}$ compost did have quite a few significant results in the forest-guinea savannah zone. In particular, 0 kg $ha^{-1}$ compost was found significant for EOC, TEN, EON, $Na^{+}$, $Mg^{2+}$, $Ca^{2+}$.

For TEN, within the 0 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ compost had significantly more TEN than all N treatments and 6000 kg $ha^{-1}$ compost (Table 22). For measured EON, 0 kg $ha^{-1}$ compost had significantly more EON than all other treatments (Table 22). For EOC, in the 0 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ compost had significantly more EOC than 140 kg $ha^{-1}$ N (Table 22). Also in the 0 kg $ha^{-1}$ P plots, findings show that 0 kg $ha^{-1}$ compost had significantly more extractable $Na^+$ than 6000 kg $ha^{-1}$ compost (Table 22). Extractable $Mg^{2+}$ was also found to be significantly higher within 0 kg $ha^{-1}$ P plots, with 0 kg $ha^{-1}$ compost having significantly more extractable soil $Mg^{2+}$ than 0 and 70 kg $ha^{-1}$ N treatments (Table 22). Within the 40 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ compost, had significantly more extractable $Mg^{2+}$ than 140 kg $ha^{-1}$ N plots (Table 22). Lastly, in the 0 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ compost had significantly more extractable $Ca^{2+}$ than 70 kg $ha^{-1}$ N.

### 3.3.5.8 3000 kg ha$^{-1}$ Compost

Compared to the coastal savannah and forest agro-ecosystem, the application of 3000 kg ha$^{-1}$ compost did not have as many significant results. However, 3000 kg ha$^{-1}$ compost did have some significant effects on $PO_4$-P, EOC and $K^+$.

3000 kg ha$^{-1}$ compost (17.2±5.0) was also found to have significantly more extractable soil $PO_4$-P than 70 kg ha$^{-1}$ N (8.0±3.3), 140 kg ha$^{-1}$ N (8.8±3.9) and 0 kg ha$^{-1}$ compost (7.1±1.3) in the 20 kg ha$^{-1}$ P plots. For extractable EOC, in the 20 kg ha$^{-1}$ P plots, 3000 kg ha$^{-1}$ compost had significantly more than 0 kg ha$^{-1}$ N. Lastly, for extractable soil $K^+$, 3000 kg ha$^{-1}$ compost had significantly more EOC than all treatments except 6000 kg ha$^{-1}$ in the 0kg ha$^{-1}$ P plots. Within the 20 kg ha$^{-1}$ plots, 3000 kg ha$^{-1}$ had significantly more extractable $K^+$ than 0 and 70 kg ha$^{-1}$ N and 0 kg ha$^{-1}$ compost, while in the 40 kg ha$^{-1}$ P plots; 3000 kg ha$^{-1}$ compost had significantly more extractable $K^+$ than 70 and 140 kg ha$^{-1}$ (Table 22).

### 3.3.5.9 6000 kg ha$^{-1}$ Compost

The application of 6000 kg ha$^{-1}$ of compost did have a significant effect on $NO_3$-N, $PO_4$-P, EOC, TEN, EON, $K^+$, $Mg^{2+}$ and $Ca^{2+}$.

For extractable $NO_3$-N, in the 20 kg ha$^{-1}$ P plots, 6000 kg ha$^{-1}$ compost had significantly more extractable $NO_3$-N than 0 kg ha$^{-1}$ N after two years of treatments (Table 22). 6000 kg ha$^{-1}$ compost had significantly more EON than 0 kg ha$^{-1}$ N in the 20 kg ha$^{-1}$ P plots (Table 22).

In the 0 kg ha$^{-1}$ P plots, 6000 kg ha$^{-1}$ compost had significantly more extractable soil $PO_4$-P than 70 and 140 kg ha$^{-1}$ N. However, in the 20 kg ha$^{-1}$ P plots for 6000 kg ha$^{-1}$ compost had significantly more extractable $PO_4$-P than 70 and 140 kg ha$^{-1}$ N and 0 kg ha$^{-1}$ compost (Table 22).

For EOC, within the 20 kg ha$^{-1}$ P plots, 6000 kg ha$^{-1}$ N was found to have significantly more EOC than 0 and 70 kg ha$^{-1}$ N treatments (Table 22). While in the 0 kg ha$^{-1}$ P plots, 6000 kg ha$^{-1}$ compost had significantly more EOC than 140 kg ha$^{-1}$ N.

For extractable K+, 6000 kg ha$^{-1}$ compost again was found to have significantly more extractable soil K+ than all other treatments except for 3000 kg ha$^{-1}$ compost in the 0 kg ha$^{-1}$ plots, while in the 20 kg ha$^{-1}$ plots it had significantly more than 0 and 70 kg ha$^{-1}$ N and 0 kg ha$^{-1}$ compost. However, in the 40 kg ha$^{-1}$ P plots, it had significantly more EOC than 70 and 140 kg ha$^{-1}$ N (Table 22). Lastly, in the forest-guinea savannah transition agro-ecosystem 0 kg ha$^{-1}$ P plots, 6000 kg ha$^{-1}$ compost had significantly more extractable soil $Mg^{2+}$ than 0 and 70 kg ha$^{-1}$ N while in the 40 kg ha$^{-1}$ plots, 6000 kg ha$^{-1}$ compost had significantly more than 70 kg ha$^{-1}$ N and 0 kg ha$^{-1}$ compost (Table 22).

### 3.3.6 Effect of phosphorus and nitrogen / compost amendments on soil nutrients in the guinea savannah

Univariate analysis of variance found significant effects of N amendments on $NO_3$-N ($p = 0.01$) and $K^+$ ($p = 0.00$) in the guinea savannah agro-ecosystem. P amendments had no significant effect and there was also no significant interaction effect between P and N amendments (Table 23).

Concentrations of nutrients in the Guinea savannah ranged from 8.0±2.1 to 22.9±10.0 for mg $NO_3$-N $kg^{-1}$, $NH_4$-N concentrations ranged from 6.8±2.2 to 19.3±13.7 mg $kg^{-1}$ and EON concentrations ranged from 0.0±0.0 to 5.1±4.6 mg $kg^{-1}$. $PO_4$-P concentrations ranged from 1.6±0.6 to 58.9±98.1 mg $kg^{-1}$ and EOC concentrations ranged from 39.6±2.9 to 76.8±35.7 mg $kg^{-1}$. Cation concentrations ranged from 31.7±4.8 to 99.7±59.3 mg $Na^+$ $kg^{-1}$ from 32.0±3.7 to $^b$71.3±32.4 mg $K^+$ $kg^{-1}$, from 52.2±13.4 to 82.0±4.2 mg $Mg^{2+}$ $kg^{-1}$ and from 204.8±19.7 to 456.3±383.7 mg $Ca^{2+}$ $kg^{-1}$ (Table 24).

Table 23. Results of univariate analysis of variance in the forest –guinea savannah transition agro-ecosystem. *Significant at p < 0.10 and **Significant at < 0.05. n = 54

| Treatment | $NO_3$-N | | $K^+$ | |
|---|---|---|---|---|
| | F Value | p value | F Value | p value |
| P | 1.38 | 0.27 | 1.29 | 0.29 |
| N/Compost | 3.4 | **0.01**** | 9.59 | **0.00**** |
| P x N/Compost | 1.12 | 0.38 | 0.33 | 0.97 |

3.3.6.1 0 kg $ha^{-1}$ Phosphate (P)

In the guinea savannah agro-ecosystem, the application of 0 kg $ha^{-1}$ P was found to have significant results in extractable soil $NO_3$-N and $K^+$. In the 140 kg $ha^{-1}$ N plots, 40 kg $ha^{-1}$ P had significantly less extractable soil $K^+$ than 0 kg $ha^{-1}$ P, while in the 6000 kg $ha^{-1}$ compost plots, 0 kg $ha^{-1}$ had significantly more extractable $NO_3$-N than 40 kg $ha^{-1}$ P (Table 24).

### 3.3.6.2 20 kg $ha^{-1}$ Phospahte (P)

In the guinea savannah agro-ecosystem, the application of 20 kg $ha^{-1}$ P had a significant effect on soil $NO_3$-N, EON, $PO_4$-P and EOC.

Within 70 kg $ha^{-1}$ N treatments, 20 kg $ha^{-1}$ P (15.7±1.9) also had significantly more extractable $NO_3$-N than 40 kg $ha^{-1}$ P (10.7±2.8). Similarly, for EON, 20 kg $ha^{-1}$ P had significantly more than both 0 and 40 kg $ha^{-1}$ P within the 70 kg $ha^{-1}$ N treatments, and significantly more EON than 0 kg $ha^{-1}$ P in the 140 kg $ha^{-1}$ N treatments (Table 24).

The 20 kg $ha^{-1}$ P treatment had significantly higher concentrations of $PO_4$-P, (4.0±1.6 mg P $kg^{-1}$) than the 0 kg $ha^{-1}$ P treatment (1.6±0.6 mg P $kg^{-1}$) within the 70 kg $ha^{-1}$ N sub-treatments. The 20 kg $ha^{-1}$ P treatment also had significantly more extractable soil EOC than observed for the 0 kg $ha^{-1}$ P treatment within the 70 kg $ha^{-1}$ N sub-treatment (Table 24).

### 3.3.6.3 40 kg $ha^{-1}$ Phosphate (P)

The application of 40 kg $ha^{-1}$ of P also did not have much significant effect on extractable soil nutrients in the Guinea savannah agro-ecosystem. However, there was some significance difference found in concentrations of EOC and $Na^+$. 40 kg $ha^{-1}$ P had significantly more extractable soil EOC than 0 kg $ha^{-1}$ P in the 0 kg $ha^{-1}$ compost plots (Table 24). 40 kg $ha^{-1}$ P also had significantly more extractable soil $Na^+$ than 20 kg $ha^{-1}$ P in the 70 kg $ha^{-1}$ N sub plots (Table 24).

3.3.6.4 0 kg $ha^{-1}$ N

In the guinea savannah, the application of 0 kg $ha^{-1}$ N did not have much significant impact on extractable soil nutrients. However, some significance was found in soil $PO_4$-P, EOC and $Na^+$. For extractable soil $PO_4$-P, 70 kg $ha^{-1}$ N was found to have significantly less extractable soil $PO_4$-P than 0 kg $ha^{-1}$ N within plots receiving 0 kg $ha^{-1}$ P (Table 24). Also, in the 20 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ N (9.4±6.4) had significantly more extractable $PO_4$-P than 140 kg $ha^{-1}$ N (2.6±0.3). For EOC, within the 0 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ N had significantly more EOC than 0 kg $ha^{-1}$ compost (Table 24). However, in the 20 kg $ha^{-1}$ P plots, 0 kg $ha^{-1}$ had significantly more extractable $Na^+$ than 70 kg $ha^{-1}$ N (Table 24).

3.3.6.5 70 kg $ha^{-1}$ N

The application of 70 kg $ha^{-1}$ N also did not create much significant effect after 2 years of treatments. However there was some significance found in extractable soil $NO_3$-N, TEN EON and EOC.

In the 20 kg $ha^{-1}$ P plots, 70 kg $ha^{-1}$ N had significantly more extractable $NO_3$-N than 0 and 3000 kg $ha^{-1}$ compost as well as 0 and 140 kg $ha^{-1}$ N (Table 24). However, for TEN, in the 20 kg $ha^{-1}$ P plots, 70 kg $ha^{-1}$ N had significantly more TEN than 0 kg $ha^{-1}$ N (Table 24). This is similar for EON, where 70 kg $ha^{-1}$ N had significantly more EON than 0 kg $ha^{-1}$ N and 6000 kg $ha^{-1}$ compost (Table 24). Lastly, for EOC, in the 20 kg $ha^{-1}$ P plots, 70 kg $ha^{-1}$ N had significantly more EOC than 0 kg $ha^{-1}$ compost (Table 24).

### 3.3.6.6 140 kg ha$^{-1}$ N

The application of 140 kg ha$^{-1}$ N had the most effect on extractable soil nutrients in the Guinea savannah agro-ecosystem. Under 140 kg ha$^{-1}$ N, there were significant differences in extractable $NO_3$-N, TEN, EON and EOC.

Within the 0 kg ha$^{-1}$ P plots, 140 kg ha$^{-1}$ N had significantly more extractable $NO_3$-N than 0 kg ha$^{-1}$ N, as well as, 0 and 3000 kg ha$^{-1}$ compost (Table 24). For TEN, within 20 kg ha$^{-1}$ P plots, 140 kg ha$^{-1}$ N had significantly more TEN than 0 kg ha$^{-1}$ N and 6000 kg ha$^{-1}$ compost (Table 24). However, 140 kg ha$^{-1}$ N also had significantly more EON than 0 kg ha$^{-1}$ N and 6000 kg ha$^{-1}$ compost in the 20 kg ha$^{-1}$ P plots.

In the 0 kg ha$^{-1}$ P plots, 140 kg ha$^{-1}$ N had significantly more extractable soil EOC than 0 kg ha$^{-1}$ compost (Table 24).

Table 24. Soil nutrients in the Guinea Savannah agro-ecosystem. ± = standard deviation. Differences in superscript lowercase letters (abc) within each Phosphorus group shows significant effect of Nitrogen/Compost applications at $p<0.05$. Differences in superscript letters (xyz) within Nitrogen/Compost groups shows a significant effect of Phosphorus application at $p<0.05$[8]

| P | N/Compost | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| kg ha$^{-1}$ | kg ha$^{-1}$ | mg kg$^{-1}$ | | | | | | | | | |
| 0 | 0 | $^{a}$8.0±2.1 | 17.1±21.6 | $^{bc}$4.0±1.7 | $^{b}$60.3±11.6 | 25.3±27.8 | 2.3±4.0 | 37.8±10.7 | $^{a}$44.3±6.6 | $^{a}$57.1±12.9 | $^{a}$213.5±45.2 |
| 0 | 70 | 14.1±11.4 | 10.4±6.9 | $^{xa}$1.6±0.6 | $^{x}$47.0±5.8 | 22.1±11.2 | $^{x}$0.0±0.0 | 60.2±32.9 | $^{a}$44.7±18.7 | 61.7±23.0 | 242.5±101.5 |
| 0 | 140 | $^{c}$22.9±10.0 | 13.9±6.6 | $^{ab}$2.8±1.0 | $^{b}$66.4±19.1 | 32.8±10.6 | $^{x}$0.0±0.0 | 99.7±59.3 | $^{ya}$42.6±3.6 | $^{a}$52.2±13.4 | $^{xa}$204.8±19.7 |
| 0 | 0 | $^{ab}$10.2±2.1 | 7.7±6.6 | $^{ab}$3.0±1.7 | $^{xa}$39.6±2.9 | 19.4±5.9 | 2.4±3.5 | 52.0±26.9 | $^{a}$41.5±14.9 | $^{a}$59.8±5.5 | $^{a}$229.9±14.2 |
| 0 | 3000 | $^{b}$12.4±2.5 | 10.8±12.6 | $^{b}$2.8±0.4 | 43.2±9.6 | 22.1±9.8 | 0.4±0.7 | 50.4±33.0 | $^{a}$46.7±6.8 | $^{a}$58.1±11.8 | $^{a}$234.9±37.1 |
| 0 | 6000 | $^{yc}$16.5±4.1 | 15.1±16.1 | $^{c}$8.1±3.7 | 76.8±35.7 | 30.0±17.6 | 0.5±0.9 | 38.1±5.9 | $^{b}$78.6±3.0 | $^{b}$82.0±4.2 | $^{b}$355.6±49.0 |
| 20 | 0 | $^{ab}$10.2±3.7 | 6.8±2.2 | $^{b}$9.4±6.4 | 51.3±11.5 | $^{a}$14.6±1.3 | $^{a}$0.0±0.0 | $^{b}$44.8±4.2 | 37.7±10.3 | 60.0±7.6 | 224.9±1.5 |
| 20 | 70 | $^{yc}$15.7±1.9 | 12.9±11.4 | $^{y}$4.0±1.6 | $^{yb}$66.9±9.9 | $^{bc}$32.9±15.0 | $^{yb}$5.1±4.6 | $^{xa}$31.7±4.8 | $^{a}$32.0±3.7 | 61.6±20.0 | 231.9±44.1 |
| 20 | 140 | $^{ab}$12.0±1.9 | 7.8±2.8 | $^{a}$2.6±0.3 | 65.2±12.1 | $^{c}$23.5±5.0 | $^{yb}$4.7±4.2 | 48.5±16.8 | 38.1±4.8 | 59.3±6.8 | 232.2±21.3 |
| 20 | 0 | $^{a}$9.7±1.9 | 8.3±4.7 | 2.5±0.8 | $^{a}$44.9±15.7 | 17.2±5.6 | 1.0±1.8 | 35.4±18.9 | 34.0±9.0 | 58.4±12.5 | 218.0±25.2 |
| 20 | 3000 | $^{ab}$9.0±3.1 | 11.2±8.7 | 12.2±14.6 | 62.9±25.3 | 19.3±10.7 | 0.9±1.6 | 58.1±28.9 | $^{b}$53.9±17.4 | 59.6±18.8 | 231.2±80.1 |
| 20 | 6000 | $^{bc}$13.1±1.7 | 7.6±3.0 | 7.2±5.8 | 56.3±8.0 | $^{ab}$16.9±1.8 | $^{a}$0.0±0.0 | $^{b}$59.1±20.4 | $^{b}$71.3±32.4 | 67.0±22.3 | 255.7±76.7 |
| 40 | 0 | 10.2±2.0 | 10.1±8.8 | 58.9±98.1 | 60.6±15.0 | 21.8±7.6 | 2.2±3.3 | 64.3±45.9 | 38.6±11.7 | 63.4±11.6 | 456.3±383.7 |
| 40 | 70 | $^{x}$10.7±2.8 | 9.5±7.5 | 2.5±1.1 | 50.6±18.0 | 17.4±9.1 | $^{x}$0.0±0.0 | $^{y}$43.3±7.6 | $^{ab}$33.1±4.4 | 53.7±1.8 | 229.6±5.8 |
| 40 | 140 | 17.7±8.6 | 19.3±13.7 | $^{a}$2.3±0.6 | 76.6±32.9 | 37.0±21.5 | 1.3±1.5 | 43.6±17.6 | $^{xa}$29.5±6.2 | 55.1±8.3 | $^{y}$248.2±27.2 |
| 40 | 0 | 10.8±1.5 | 17.7±10.5 | 5.3±3.5 | $^{y}$64.5±16.9 | 26.6±12.1 | 0.0±0.0 | 38.7±6.6 | $^{ab}$37.6±10.1 | 57.3±9.7 | 229.2±23.4 |
| 40 | 3000 | 12.2±3.5 | 12.2±8.8 | 6.1±3.7 | 63.0±14.5 | 25.5±9.0 | 2.2±3.7 | 35.5±10.3 | $^{bc}$52.6±17.7 | 64.4±9.9 | 384.2±195.1 |
| 40 | 6000 | $^{x}$10.0±2.8 | 12.9±15.5 | $^{b}$7.5±4.2 | 51.6±19.4 | 21.7±12.7 | 1.8±3.2 | 40.5±2.2 | $^{c}$65.5±19.9 | 70.0±25.3 | 287.6±76.9 |

[8] EOC = Extractable Organic C, TEN = Total Extractable N, EON = Extractable Organic N

### 3.3.6.7 0 kg $ha^{-1}$ Compost

The application of 0 kg $ha^{-1}$ compost had no significant effects on extractable soil nutrients.

### 3.3.6.8 3000 kg $ha^{-1}$ Compost

In comparison to the other three agro-ecosystems, 3000 kg $ha^{-1}$ compost had significantly less effect in the guinea savannah agro-ecosystem. Nevertheless, there was significance found in extractable soil $NO_3$-N, $PO_4$-P and $K^+$.

Within the 0 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost had significantly higher extractable $NO_3$-N than 0 kg $ha^{-1}$ N and significantly more extractable $PO_4$-P than 70 kg $ha^{-1}$ N (Table 24). However, in the 20 kg $ha^{-1}$ P plots, 3000 kg $ha^{-1}$ compost had significantly more extractable soil $K^+$ than 70 $ha^{-1}$ N treatments (Table 24).

### 3.3.6.9 6000 kg $ha^{-1}$ Compost

In comparison to the other three agro-ecosystems, 6000 kg $ha^{-1}$ compost had significantly less effect in the guinea savannah agro-ecosystem. Nevertheless, there was significance found for extractable $NO_3$-N, $PO_4$-P, EOC, $Na^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$.

Within the 0 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly higher extractable $NO_3$-N than 0 kg $ha^{-1}$ N and 0 and 3000 kg $ha^{-1}$compost (Table 24). However in the 20 kg $ha^{-1}$ plots, 6000 kg $ha^{-1}$ compost had significantly more $NO_3$-N than 0 kg $ha^{-1}$ compost. For extractable soil $PO_4$-P, in the 0 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable soil $PO_4$-P than 70 and 140 kg $ha^{-1}$ N and 0 and 3000 kg

$ha^{-1}$ compost (Table 24). However, within the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable soil $PO_4$-P than 140 kg $ha^{-1}$ N (Table 24). In the 20 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable soil $Na^+$ than 70 kg $ha^{-1}$ N (Table 24).

6000 kg ha $^{-1}$ did have a significant effect on extractable soil $K^+$. In the guinea savannah agro-ecosystem, 0 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost (78.6±3.0) had significantly more extractable $K^+$ than all other treatments (Table 24). While in the 20 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly higher $K^+$ than 70 kg $ha^{-1}$ N (Table 24). However, in the 40 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ had significantly more extractable soil $K^+$, than 70 and 140 kg $ha^{-1}$ N plots and 0 kg $ha^{-1}$ compost (Table 24). Lastly, in the 0 kg $ha^{-1}$ P plots, 6000 kg $ha^{-1}$ compost had significantly more extractable soil $Mg^{2+}$ and $Ca^{2+}$ than all other treatments except 70 kg $ha^{-1}$ N (Table 24).

### 3.3.7 Modeling of treatments and environmental factors to produce a predictive model of soil extractable nutrients across Ghana.

Only extractable soil K could be predicted across the four agro-ecosystems in Ghana. Using a backward stepwise multiple regression analysis with agro-ecosystem, P amendment and N amendment as independent variables, the best model for predicting extractable soil $K^+$ across Ghana included agro-ecosystem type and N amendment. Here, 58% of the variance in extractable soil $K^+$ was explained by agro-ecosystem and N application ($p < 0.0001$; Eq. 1).

Eq. 1 $K^+$ (mg $kg^{-1}$) = 85.365 + (-20.303*Agro-ecosystem) + (10.125*N application)

Using the model (Eq. 1) to predict of soil extractable $K^+$ showed some scatter, but the model appeared to be fairly robust up to 150 kg $K^+$ $ha^{-1}$ (Figure 2).

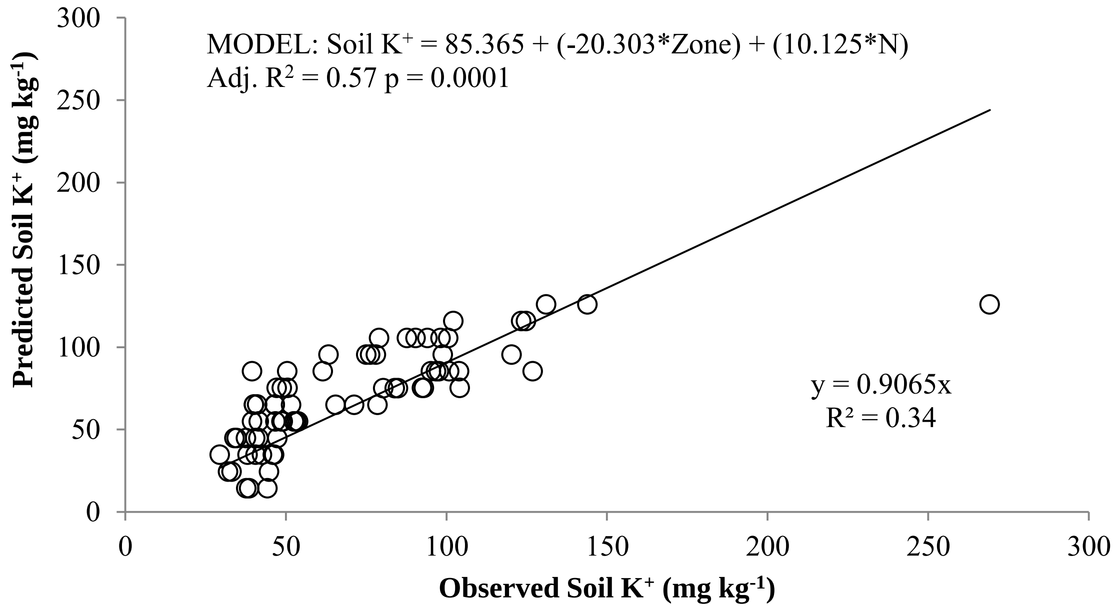


Figure 2. Observed and predicted extractable soil $K^+$ across the four agro-ecosystems in Ghana

Predictive models for other soil nutrients were more successful when removing the agro-ecosystem term and examining the predictive ability of N and P amendments on soil nutrient status within each agro-ecosystem (Table 25).

#### 3.3.7.1 Coastal savannah

In the coastal savannah agro-ecosystem of Ghana, the only extractable soil nutrient that could be predicted by soil P and N amendments was $PO_4$-P, while N amendments were found to be a good predictor for soil EOC, $Na^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$. Although nutrients modeled were significant ($p < 0.05$) the adjusted $R^2$ values ranged between 0.22-0.29 explaining low variance in soil nutrient status. This indicated that in the coastal savannah, the mean change in response for one unit of Nitrogen or Phosphorus would have a significant effect on EOC and other cations.

Table 25: Model Coefficients across all four agro-ecosystems. [9]

| | | Model Coefficients | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Agro-Ecosystem | Soil Extract | Constant | P Treatment | N Treatment | $R^2$ | Adj $R^2$ | F Value | p = |
| Coastal Savannah | $PO_4$-P | 0.108 | 13.534 | 8.46 | 0.34 | 0.25 | 3.79 | 0.047 |
| | EOC | 39.953 | | 5.151 | 0.31 | 0.27 | 7.2 | 0.016 |
| | $Na^+$ | 30.183 | | 3.716 | 0.32 | 0.28 | 7.51 | 0.015 |
| | $K^+$ | 66.522 | | 13.755 | 0.33 | 0.29 | 7.9 | 0.013 |
| | $Mg^{2+}$ | 55.667 | | 8.84 | 0.32 | 0.28 | 7.55 | 0.014 |
| | $Ca^{2+}$ | 438.587 | | 38.75 | 0.27 | 0.22 | 5.84 | 0.03 |
| Forest | $NO_3$-N | 7.866 | 1.355 | | 0.23 | 0.19 | 4.85 | 0.04 |
| | TEN | 12.761 | 3.857 | | 0.3 | 0.26 | 6.84 | 0.02 |
| | $K^+$ | 29.744 | | 8.062 | 0.69 | 0.67 | 35.84 | 0.001 |
| | $Mg^{2+}$ | 359.244 | -20.625 | | 0.44 | 0.41 | 12.6 | 0.003 |
| Transition | $NH_4$-N | 3.687 | 1.00 | 0.565 | 0.36 | 0.28 | 4.24 | 0.035 |
| | $PO_4$-P | -4.198 | 17.207 | | 0.33 | 0.29 | 7.91 | 0.013 |
| | EOC | 44.172 | 5.287 | 2.647 | 0.54 | 0.47 | 8.61 | 0.003 |
| | TEN | 11.856 | | 1.958 | 0.28 | 0.23 | 6.14 | 0.025 |
| | $K^+$ | 16.704 | | 12.902 | 0.7 | 0.68 | 36.7 | 0.0001 |
| | $Mg^{2+}$ | 75.63 | | 5.035 | 0.39 | 0.35 | 10.25 | 0.006 |
| | $Ca^{2+}$ | 424.211 | | 84.914 | 0.33 | 0.29 | 7.88 | 0.013 |
| Guinea Savannah | $K^+$ | 25.458 | | 5.78 | 0.54 | 0.51 | 18.69 | 0.001 |
| | $Mg^{2+}$ | 53.932 | | 2.06 | 0.28 | 0.24 | 6.24 | 0.024 |

### 3.3.7.2 Forest

In the forest agro-ecosystem, $NO_3$-N, TEN and $Mg^{2+}$ were able to be estimated by P application. Similar to the coastal savannah, all models were significant at $p < 0.05$ while adjusted $R^2$ values were 0.19, 0.26 and 0.41 for $NO_3$-N, TEN and $Mg^{2+}$ respectively. The only nutrient in the forest zone to be successfully predicted by N was $K^+$. Sixty-nine percent of the variance in soil $K^+$ concentrations was explained by N applications (p <

[9] EOC = Extractable Organic C, TEN = Total Extractable N

0.0001). These results suggest that it may be quite possible to create a predictive model for soil extractable $K^+$ using environmental factors and N application in the forest agro-ecosystem.

#### 3.3.7.3 Forest-guinea savannah transition

Within the forest-guinea savannah transition agro-ecosystem, nutrients were found to be predicted by either P or N amendments. Here $PO_4$-P was predicted by just P application, $NH_4$-N and EOC by N and P application, while TEN, $K^+$, $Mg^{2+}$ and $Ca^{2+}$ could be predicted by N. Similar to the other agro-ecosystems, all models were significant at $p < 0.05$. However, the model for predicting soil $K^+$ was highly significant ($p < 0.0001$) with an adjusted $R^2$ of 0.68. This result is almost identical to the forest agro-ecosystem and suggests that there is a strong relationship between N and $K^+$ in the two agro-ecosystems containing forest species.

#### 3.3.7.4 Guinea savannah

Only $K^+$ and $Mg^{2+}$ could be predicted by N application of soil amendments in the Guinea savannah agro-ecosystem. Similar to the other agro-ecosystems, models were significant at $p < 0.05$ (Table 25). The adjusted $R^2$ values were 0.51 and 0.24 for $K^+$ and $Mg^{2+}$ respectively.

### 3.3.8 Correlations among soil extractable nutrients

In some cases it can prove to be effective to predict certain soil nutrients using analyzed soil nutrients. Here it is important to examine correlations among extracted soil nutrients so that correlations can be developed into predictive models or, so that indications of mechanisms resulting in specific soil nutrient concentration can be examined. In the coastal savannah agro-ecosystem several correlations were found (Table 26). $NO_3$-N was significantly correlated with $NH_4$-N ($R = 0.51$; $p < 0.05$). Both $NO_3$-N and $NH_4$-N were significantly correlated with EOC ($R = 0.80$ and $0.66$; $p < 0.01$), and cations ($K^+$, $Mg^{2+}$, and $Ca^{2+}$) ($R = 0.78$-$0.79$ and $0.66$-$0.75$; $p < 0.01$). All extractable cations except $Na^+$ were strongly and significantly correlated to EOC in the coastal savannah (Table 26).

Table 26. Correlations among soil nutrients extracted with 0.1 M HCl in the Coastal Savannah agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *significant at $p < 0.05$ and **significant at $p < 0.01$

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | 0.51* | 0.80** | -0.13 | 0.07 | 0.78** | 0.78** | 0.79** |
| $NH_4$-N | | 0.66** | -0.03 | -0.08 | 0.75** | 0.66** | 0.67** |
| EOC | | | 0.31 | 0.34 | 0.91** | 0.88** | 0.87** |
| EON | | | | 0.29 | 0.02 | 0.03 | 0.03 |
| $Na^+$ | | | | | 0.33 | 0.19 | 0.16 |
| $K^+$ | | | | | | 0.94** | 0.94** |
| $Mg^{2+}$ | | | | | | | 0.98** |

Similar correlations among extractable soil nutrients were not apparent in the forest agro-ecosystem (Table 27). Here $NO_3$-N was not correlated with $NH_4$-N nor was $NO_3$-N and $NH_4$-N correlated with EOC (Table 27). Instead, $NO_3$-N had a moderate but significant correlation with EON ($R = 0.55$; $p < 0.05$) and both $NO_3$-N and $NH_4$-N had a moderate but significant correlation with extractable soil $K^+$ ($R = 0.47$ and $-0.52$; $p < 0.05$). While $NO_3$-N was positively correlated with $K^+$, $NH_4$-N was inversely correlated with $K^+$ (Table 27). Of the cations, only extractable $Ca^{2+}$ was significantly correlated to EOC ($R = 0.70$; $p < 0.001$) but it was also correlated with EON (Table 27). The accepted relationship between EOC and EON in many forest studies also held in the forest agro-ecosystem where a moderate but significant correlation was observed ($R = 0.58$; $p < 0.05$).

Table 27. Correlations among soil nutrients extracted with 0.1 M HCl in the Forest agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *significant at p < 0.05 and **significant at p < 0.01

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | -0.14 | 0.41 | 0.55* | -0.13 | 0.47* | -0.15 | 0.24 |
| $NH_4$-N | | -0.27 | -0.08 | -0.18 | -0.52* | 0.34 | -0.25 |
| EOC | | | 0.58* | -0.31 | 0.34 | -0.06 | 0.70** |
| EON | | | | -0.13 | -0.09 | -0.08 | 0.47* |
| $Na^+$ | | | | | 0.00 | -.032 | -0.40 |
| $K^+$ | | | | | | -0.03 | 0.04 |
| $Mg^{2+}$ | | | | | | | 0.08 |

Different correlations among extractable soil nutrients also occurred in the forest-savannah transition agro-ecosystem (Table 28). $NO_3$-N was moderately but significantly correlated with $Mg^{2+}$ only (R = 0.51; $p < 0.05$). $NH_4$-N on the other hand displayed relatively strong and significant positive correlations with EOC (R = 0.60; $p < 0.01$) and EON (R = 0.70; $p < 0.01$). A strong and significant correlation was observed for EOC and EON (R = 0.76; $p < 0.01$) and EOC and cations (Table 28) with the correlation of EOC and $Ca^{2+}$ the strongest (R = 0.78; $p < 0.01$). $Ca^{2+}$ and $Mg^{2+}$ often show very strong correlations in soil extracts and in the transition zone this was also the case (R = 0.68; $p < 0.01$), though not such a high correlation as was observed in the coastal savannah (Table 26). The $K^+$ and $Mg^{2+}$ was also significant in the transition zone (Table 28) but not as strong as observed in the coastal savannah (Table 26).

Table 28. Correlations among soil nutrients extracted with 0.1 M HCl in the Forest-Savannah transition agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *significant at $p < 0.05$ and **significant at $p < 0.01$

| | $NH_4$.N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$.N | 0.32 | 0.43 | 0.35 | 0.23 | 0.31 | $0.51^{*}$ | 0.28 |
| $NH_4$.N | | $0.60^{**}$ | $0.71^{**}$ | -0.21 | 0.26 | 0.11 | 0.26 |
| DOC | | | $0.76^{**}$ | 0.16 | $0.59^{**}$ | $0.58^{*}$ | $0.78^{**}$ |
| DON | | | | -0.11 | 0.22 | 0.27 | 0.39 |
| $Na^+$ | | | | | 0.32 | 0.38 | 0.18 |
| $K^+$ | | | | | | $0.69^{**}$ | $0.49^{*}$ |
| $Mg^{2+}$ | | | | | | | $0.68^{**}$ |

Fewer correlations among extractable soil nutrients were observed in the Guinea savannah agro-ecosystem (Table 29). $NO_3$-N had a moderate but significant correlation with EOC ($R = 0.50$; $p < 0.05$) and $Na^{2+}$ ($R = 0.50$; $p < 0.05$). $NH_4$-N also had a moderate to strong positive correlation with EOC ($R = 0.65$; $p < 0.01$) which was similar to that observed in the coastal savannah and forest-savannah transition agro-ecosystems (Tables 26 and 28). The correlation between EOC and EON was absent in the guinea savannah (Table 29) and was similar to that observed in the coastal savannah (Table 26). The strongest correlation among soil extracts was between $K^+$ and $Mg^{2+}$ ($R = 0.82$; $p < 0.01$) reflecting a similar correlation to that observed in the coastal savannah agro-ecosystem (Table 26).

Table 29. Correlations among soil nutrients extracted with 0.1 M HCl in the Guinea Savannah agro-ecosystem. EOC=Extractable Organic C, EON=Extractable Organic N. *significant at $p < 0.05$ and **significant at $p < 0.01$

| | $NH_4$-N | EOC | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|---|---|---|
| $NO_3$-N | 0.34 | 0.50* | -0.10 | 0.50* | 0.03 | -0.01 | -0.06 |
| $NH_4$-N | | 0.65** | -0.03 | -0.14 | -0.01 | -0.02 | 0.03 |
| DOC | | | 0.21 | -0.01 | 0.12 | 0.22 | 0.26 |
| DON | | | | -0.33 | -0.25 | 0.04 | 0.11 |
| $Na^+$ | | | | | 0.03 | -0.28 | -0.06 |
| $K^+$ | | | | | | 0.82** | 0.34 |
| $Mg^{2+}$ | | | | | | | 0.57* |

## 3.4 Discussion

The use of inorganic fertilizer application in West Africa tends to be reserved for cash crops rather than sustaining smallholder farms. Although the application of compost along with mineral fertilizers has been recommended in W. Africa, there is a continuing debate as to whether compost quality rather than quantity has a greater effect on improving soil chemical and physical properties (Bationo et al., 2006; Ouedraogo et al. 2006; Fonte et al. 2009). Not completed in this study was a thorough examination of the differences between the application of urea and compost in terms of univariate analysis of variance which would have shed some light and allowed recommendations for the use of compost over urea for maintaining soil nutrient status in specific agro-ecosystems. This analysis will be completed for manuscripts submitted for publication resulting from this thesis. However, results of this study in Ghanaian agro-ecosystems suggested that the application of either mineral fertilizer or compost will increase extractable soil nutrients compared to not applying any soil N amendment. This was demonstrated by the tendency for 0 kg ha$^{-1}$ P+N or P+Compost to have significantly less extractable nutrients than other treatments in each agro-ecosystem. Ouedraogo et al. (2006) reported that combining recalcitrant organic amendments and N fertilizer was the best option for sustaining crop production, improving soil particulate organic matter and reducing soil carbon decline. Bationo et al. (2006) further appealed for the application of both inorganic fertilizer and organic matter along with other site-specific integrated soil fertility management systems to ensure that the maximum benefits of each are realized. These suggestions are not surprising given the tendency for soils in West Africa to be low in organic carbon (<20 to 30 mg $kg^{-1}$) due to the low root growth of crops and natural vegetation but also the rapid microbial turnover rates of organic materials with high soil temperature and microfauna, particularly termites (Bationo et al., 2006; Bationo et al., 2007).

### 3.4.1 Selection of soil amendments for Ghanaian soils for improving soil nutrient status

This study demonstrated that the best combination of P and N amendments for Ghanaian agro-ecosystems depends on the specific soil nutrient or nutrient ratio needed for optimal yields. For example, highest extractable soil $NO_3$-N concentrations were observed in a combination of 0 kg $ha^{-1}$ P + 6000 kg $ha^{-1}$ compost in the coastal savannah, 40 kg $ha^{-1}$ P + 70 kg $ha^{-1}$ N in the forest, 20 kg $ha^{-1}$ P + 6000 kg $ha^{-1}$ compost in the forest-Guinea savannah transition and 0 kg $ha^{-1}$ P + 140 kg $ha^{-1}$ N in the Guinea savannah. If for example soil P needed to be increased for certain crops then optimal amendments would be of 0 kg $ha^{-1}$ P + 6000 kg $ha^{-1}$ compost in the coastal savannah, 20 kg $ha^{-1}$ P + 0 kg $ha^{-1}$ compost or 40 kg $ha^{-1}$ P + 3000 kg $ha^{-1}$ compost in the forest, 40 kg $ha^{-1}$ P + 0 kg $ha^{-1}$ N in the forest-guinea savannah and 40 kg $ha^{-1}$ P + 0 kg $ha^{-1}$ N in the guinea savannah. If however soil water retention through sequestration of C was required using EOC as a measure of % soil carbon (Figure 2), then 0 kg $ha^{-1}$ P + 6000 kg $ha^{-1}$ compost is optimal for high soil EOC in the coastal savannah, 40 kg $ha^{-1}$ P + 3000 kg $ha^{-1}$ compost in the forest, 20 kg $ha^{-1}$ P + 6000 kg $ha^{-1}$compost in the forest-Guinea savannah transition and 20 kg $ha^{-1}$ P + 70 kg $ha^{-1}$ N in the Guinea savannah. Soils in this study were not analyzed for %C and %N due to USDA restrictions on transfer of foreign soils among laboratories for analysis and there a few university laboratories that have both a soil permit which includes receipt of soils from Africa and a soil C and N analyzer. As a surrogate for this research 0.1 M HCl for EOC was used. It is unknown whether a similar relationship between EOC and %C exists in Ghanaian soils extracted with 0.1M HCl at this stage (Figure 3).

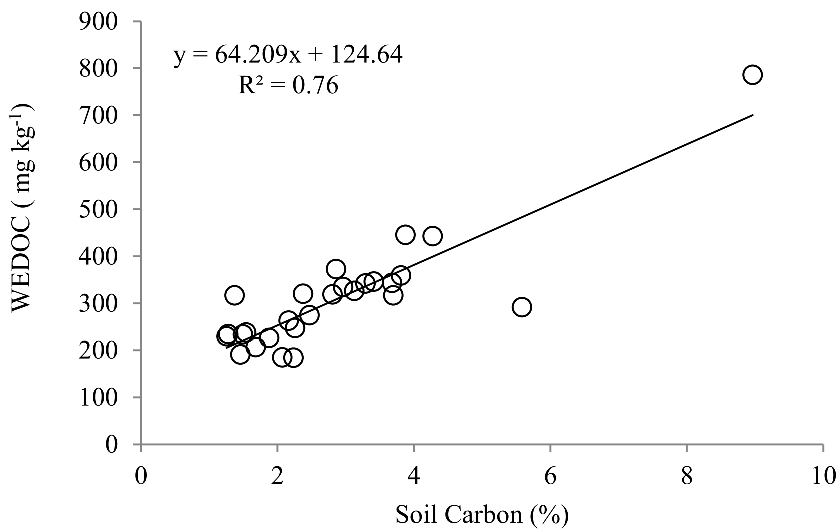


Figure 3. Relationship between water extractable soil organic carbon and % soil carbon (collected at 0-30 cm depth) measured by combustion in temperate agricultural soils in USA (Source: *unpublished data, J. A. Aitkenhead-Peterson*)

Most important is the fact that a standard soil amendment combination will not give the same results for soil nutrients in every agro-ecosystem in Ghana. Differences in environmental factors among agro-ecosystems, such as annual rainfall and its distribution, soil parent material, which ranges from igneous granite, metamorphic phyllite derived from slate and sedimentary sandstone and shalestone, is responsible for soil texture and the type of nutrients gained through weathering. All of these factors, and more, will all effect how a specific agro-ecosystem soil will respond to soil amendments. This knowledge though is not new. For decades, soil scientists have been advocating for the use of technologies that meet nutrient requirements based on soil type, farming-cropping system, farm size, availability of essential inputs and other socioeconomic factors (Lal, 1987). The goal of transforming low input subsistence farms into commercial enterprises can be achieved through gradual improvements and technological innovations appropriate for the site and the farmer (Lal, 1987).

### 3.4.2 Modeling soil nutrient status

Unlike the tillage x cropping experiment (Chapter I), a predictive model for extractable $K^+$ could be created using a backward stepwise multiple regression analysis with agro-ecosystem and N amendment as independent variables. Although 58% of the variance in extractable soil $K^+$ was explained by agro-ecosystem and N application, when looking at the forest and forest-guinea savannah transition agro-ecosystems individually 69% and 70% of variance could be explained by N treatments. This strong relationship between N application and $K^+$ could be explained by application of 3000-

6000 kg $ha^{-1}$ compost. T-Test results found both to be highly significant in extractable $K^+$ across all agro-ecosystems. Given that the compost included 1.3% $K_2O$, approximately 39-78 kg $ha^{-1}$ of $K_2O$ was applied in 3000 and 6000 kg $ha^{-1}$ compost plots versus all other plots that did not receive a $K^+$ application. This application of $K_2O$ could help explain the variance explained by N treatment and demonstrates the immediate effect that the application of a soil amendment can have.

# 4. CONCLUSIONS

## 4.1 Conclusion for the effect of tillage and cropping on extractable soil nutrients

After two years of tillage and cropping treatments, it is likely still too early to make any definitive conclusions on the effect of different tillage and cropping systems on soil nutrient concentrations across the four agro-ecosystems of Ghana. Although agro-ecosystem was shown to have a significant effect on extractable soil nutrients, a continuation of the study will better determine how different tillage and cropping systems impact soil fertility across each of the four agro-ecosystems in Ghana.

## 4.2 Conclusion for the effect of applying triple super phosphate, urea and compost on extractable soil nutrients

After two years of treatments, it is clear that the application of soil amendments tends to increase soil extractable nutrients. Nevertheless, the application of 6000 kg ha$^{-1}$ compost is beginning to show some significant effects on extractable soil nutrients in the coastal savannah, forest and forest-Guinea savannah transition zone. Given that applying 6000 kg ha$^{-1}$ provides significant amounts of macro and micronutrients (192 kg ha$^{-1}$ N, 192 kg ha$^{-1}$ $P_2O_5$, 78 kg ha$^{-1}$ $K_2O$, 2880 kg ha$^{-1}$ organic matter, 270 kg ha$^{-1}$ CaO and 120 kg ha$^{-1}$ MgO), a continuation of the study will better determine how different mineral fertilizer and compost applications impact soil fertility.

Furthermore, there is some correlation between environmental factors and N and P amendments on extractable soil nutrients across all four agro-ecosystems. Currently the ability to accurately determine nutrients is limited although $K^+$ does show promise. More data from future treatments will better determine if a predictive soil nutrient model is viable at an agro-ecosystem- or country-scale in Ghana.

Future studies may also be wise to examine soil amendment combinations on soil nutrients annually to assess whether the same combination of P and N should be applied each year. Fertilizer added in excess over the long-term can result in leaching losses and changes in soil nutrient dynamics (Matson et al., 1997).

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# APPENDIX I

## EXPERIMENT 1 : TILLAGE x CROPPING

| | | | | | | | Nutrient Mass | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
| TAMU ID | Sample Name | Zone | Plot | Rep | Till | Crop | mg/kg | | | | | | | | | |
| S04963 | Ex1 1-122 | 1 | 122 | 1 | 1 | 1 | 12.17 | 5.58 | 10.67 | 52.81 | 26.78 | 9.03 | 25.67 | 52.01 | 72.58 | 338.65 |
| S04970 | Ex1 1-221 | 1 | 221 | 2 | 1 | 1 | 8.86 | 5.80 | 13.59 | 65.06 | 24.28 | 9.63 | 17.90 | 36.85 | 85.40 | 397.08 |
| S04976 | Ex1 1-323 | 1 | 323 | 3 | 1 | 1 | 38.20 | 10.08 | 51.43 | 50.20 | 43.83 | 0.00 | 14.83 | 52.15 | 87.18 | 411.92 |
| S04965 | Ex1 1-124 | 1 | 124 | 1 | 1 | 2 | 10.98 | 6.78 | 4.71 | 58.30 | 26.20 | 8.44 | 17.85 | 34.25 | 71.37 | 356.75 |
| S04948 | Ex1 1-223 | 1 | 223 | 2 | 1 | 2 | 11.43 | 5.42 | 3.82 | 67.82 | 27.33 | 10.48 | 21.56 | 51.17 | 87.21 | 370.56 |
| S04960 | Ex1 1-322 | 1 | 322 | 3 | 1 | 2 | 10.33 | 5.17 | 9.39 | 50.28 | 12.97 | 0.00 | 17.22 | 40.61 | 101.31 | 463.77 |
| S04964 | Ex1 1-123 | 1 | 123 | 1 | 1 | 3 | 15.06 | 9.80 | 6.69 | 58.42 | 33.52 | 8.65 | 27.49 | 38.42 | 58.76 | 336.52 |
| S04949 | Ex1 1-222 | 1 | 222 | 2 | 1 | 3 | 8.73 | 5.60 | 8.56 | 56.59 | 24.99 | 10.66 | 32.11 | 39.15 | 68.82 | 299.26 |
| S04977 | Ex1 1-324 | 1 | 324 | 3 | 1 | 3 | 8.75 | 5.68 | 5.58 | 46.59 | 11.40 | 0.00 | 24.18 | 42.17 | 94.22 | 454.02 |
| S04957 | Ex1 1-121 | 1 | 121 | 1 | 1 | 4 | 12.65 | 7.80 | 13.66 | 45.84 | 21.98 | 1.53 | 19.40 | 23.52 | 70.96 | 342.56 |
| S04945 | Ex1 1-224 | 1 | 224 | 2 | 1 | 4 | 7.11 | 5.18 | 3.25 | 55.26 | 22.71 | 10.42 | 36.39 | 30.77 | 63.52 | 341.58 |
| S04975 | Ex1 1-321 | 1 | 321 | 3 | 1 | 4 | 9.81 | 5.22 | 7.21 | 57.95 | 26.48 | 11.45 | 20.79 | 20.53 | 67.42 | 319.97 |
| S04959 | Ex1 1-134 | 1 | 134 | 1 | 2 | 1 | 12.11 | 7.26 | 16.26 | 60.29 | 28.69 | 9.32 | 14.27 | 39.43 | 83.04 | 417.03 |
| S04972 | Ex1 1-234 | 1 | 234 | 2 | 2 | 1 | 8.58 | 6.36 | 11.78 | 74.95 | 27.23 | 12.29 | 24.21 | 38.92 | 58.55 | 272.04 |
| S04955 | Ex1 1-314 | 1 | 314 | 3 | 2 | 1 | 11.20 | 7.84 | 9.70 | 89.54 | 28.03 | 9.00 | 21.91 | 27.85 | 57.73 | 304.19 |
| S04966 | Ex1 1-131 | 1 | 131 | 1 | 2 | 2 | 15.78 | 6.89 | 3.73 | 56.44 | 32.58 | 9.91 | 22.89 | 40.45 | 74.28 | 320.96 |
| S04971 | Ex1 1-233 | 1 | 233 | 2 | 2 | 2 | 12.96 | 5.56 | 8.79 | 53.46 | 26.17 | 7.64 | 76.62 | 63.74 | 65.98 | 311.60 |
| S04947 | Ex1 1-312 | 1 | 312 | 3 | 2 | 2 | 9.71 | 4.71 | 4.71 | 38.84 | 12.91 | 0.00 | 12.86 | 23.06 | 44.98 | 256.60 |
| S04967 | Ex1 1-132 | 1 | 132 | 1 | 2 | 3 | 10.13 | 6.70 | 4.36 | 54.04 | 24.80 | 7.96 | 19.09 | 20.39 | 64.97 | 398.91 |
| S04958 | Ex1 1-232 | 1 | 232 | 2 | 2 | 3 | 8.67 | 6.49 | 7.42 | 51.18 | 24.29 | 9.12 | 19.72 | 21.72 | 59.48 | 295.09 |
| S04973 | Ex1 1-311 | 1 | 311 | 3 | 2 | 3 | 10.83 | 6.57 | 6.75 | 48.05 | 15.97 | 0.00 | 9.84 | 25.53 | 51.75 | 318.51 |
| S04954 | Ex1 1-133 | 1 | 133 | 1 | 2 | 4 | 8.67 | 6.63 | 6.47 | 34.99 | 18.92 | 3.62 | 21.10 | 23.01 | 77.72 | 396.59 |
| S04953 | Ex1 1-231 | 1 | 231 | 2 | 2 | 4 | 10.84 | 6.63 | 3.54 | 95.20 | 28.50 | 11.03 | 24.60 | 34.12 | 76.78 | 369.04 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S04974 | Ex1 1-313 | 1 | 313 | 3 | 2 | 4 | 10.30 | 6.71 | 10.89 | 60.55 | 26.48 | 9.46 | 13.36 | 25.63 | 55.56 | 292.58 |
| S04956 | Ex1 1-114 | 1 | 114 | 1 | 3 | 1 | 10.21 | 7.45 | 10.62 | 49.11 | 23.61 | 5.95 | 20.99 | 36.13 | 54.45 | 299.25 |
| S04969 | Ex1 1-212 | 1 | 212 | 2 | 3 | 1 | 14.73 | 7.29 | 4.16 | 52.63 | 29.45 | 7.42 | 26.42 | 33.11 | 81.29 | 401.58 |
| S04978 | Ex1 1-331 | 1 | 331 | 3 | 3 | 1 | 9.07 | 4.87 | 6.78 | 56.34 | 25.03 | 11.09 | 17.15 | 37.96 | 91.51 | 448.51 |
| S04962 | Ex1 1-112 | 1 | 112 | 1 | 3 | 2 | 10.39 | 8.20 | 4.43 | 45.83 | 23.89 | 5.30 | 22.17 | 29.31 | 64.46 | 327.39 |
| S04946 | Ex1 1-213 | 1 | 213 | 2 | 3 | 2 | 13.50 | 6.64 | 7.08 | 44.62 | 22.19 | 2.04 | 27.25 | 39.97 | 72.94 | 343.38 |
| S04950 | Ex1 1-333 | 1 | 333 | 3 | 3 | 2 | 14.08 | 5.32 | 4.47 | 56.22 | 26.98 | 7.58 | 80.89 | 52.24 | 92.05 | 449.65 |
| S04951 | Ex1 1-113 | 1 | 113 | 1 | 3 | 3 | 8.38 | 5.96 | 5.30 | 49.58 | 23.14 | 8.80 | 20.74 | 32.98 | 55.68 | 298.68 |
| S04952 | Ex1 1-214 | 1 | 214 | 2 | 3 | 3 | 11.97 | 6.12 | 11.76 | 59.52 | 26.26 | 8.18 | 17.54 | 19.97 | 92.41 | 414.17 |
| S04980 | Ex1 1-334 | 1 | 334 | 3 | 3 | 3 | 10.31 | 4.82 | 6.27 | 44.81 | 13.57 | 0.00 | 14.96 | 18.69 | 67.32 | 371.07 |
| S04961 | Ex1 1-111 | 1 | 111 | 1 | 3 | 4 | 9.54 | 5.36 | 5.16 | 62.87 | 26.19 | 11.29 | 78.18 | 63.18 | 82.07 | 439.01 |
| S04968 | Ex1 1-211 | 1 | 211 | 2 | 3 | 4 | 9.30 | 6.74 | 5.11 | 55.46 | 24.69 | 8.66 | 21.41 | 26.10 | 57.15 | 272.33 |
| S04979 | Ex1 1-332 | 1 | 332 | 3 | 3 | 4 | 11.54 | 5.15 | 10.19 | 67.73 | 32.59 | 15.90 | 27.60 | 27.71 | 112.32 | 535.04 |
| S04907 | Ex1 2-122 | 2 | 122 | 1 | 1 | 1 | 11.67 | 13.42 | 1.38 | 120.41 | 49.88 | 24.79 | 49.94 | 37.34 | 342.57 | 948.89 |
| S04905 | Ex1 2-221 | 2 | 221 | 2 | 1 | 1 | 7.99 | 6.05 | 1.97 | 118.46 | 35.43 | 21.39 | 49.71 | 37.17 | 340.98 | 944.49 |
| S04881 | Ex1 2-323 | 2 | 323 | 3 | 1 | 1 | 6.23 | 11.79 | 1.32 | 102.87 | 38.51 | 20.50 | 91.67 | 53.11 | 305.68 | 701.72 |
| S04900 | Ex1 2-124 | 2 | 124 | 1 | 1 | 2 | 11.78 | 11.75 | 1.16 | 77.29 | 39.93 | 16.40 | 113.7 | 40.32 | 297.71 | 1149.0 |
| S04888 | Ex1 2-223 | 2 | 223 | 2 | 1 | 2 | 7.78 | 6.49 | 2.48 | 79.35 | 28.69 | 14.43 | 74.55 | 39.11 | 345.89 | 1280.5 |
| S04875 | Ex1 2-322 | 2 | 322 | 3 | 1 | 2 | 8.07 | 8.55 | 6.61 | 113.26 | 36.67 | 20.05 | 30.19 | 58.36 | 308.88 | 865.41 |
| S04903 | Ex1 2-123 | 2 | 123 | 1 | 1 | 3 | 17.56 | 5.22 | 1.99 | 97.28 | 36.48 | 13.70 | 44.02 | 36.34 | 208.93 | 1716.8 |
| S04908 | Ex1 2-222 | 2 | 222 | 2 | 1 | 3 | 13.19 | 6.51 | 1.42 | 91.06 | 31.16 | 11.46 | 47.08 | 44.64 | 331.51 | 1214.8 |
| S04880 | Ex1 2-324 | 2 | 324 | 3 | 1 | 3 | 7.41 | 12.76 | 1.25 | 108.89 | 59.56 | 39.39 | 44.44 | 36.50 | 240.21 | 642.09 |
| S04899 | Ex1 2-121 | 2 | 121 | 1 | 1 | 4 | 12.90 | 16.38 | 1.50 | 81.85 | 43.06 | 13.78 | 45.31 | 36.89 | 333.75 | 1068.9 |
| S04889 | Ex1 2-224 | 2 | 224 | 2 | 1 | 4 | 5.67 | 6.07 | 2.26 | 88.43 | 29.87 | 18.13 | 67.33 | 40.31 | 294.69 | 1044.5 |
| S04890 | Ex1 2-321 | 2 | 321 | 3 | 1 | 4 | 9.28 | 7.06 | 1.90 | 210.37 | 38.51 | 22.18 | 47.15 | 69.39 | 376.81 | 1079.6 |
| S04897 | Ex1 2-134 | 2 | 134 | 1 | 2 | 1 | 9.47 | 14.33 | 1.10 | 90.09 | 51.03 | 27.23 | 51.91 | 32.13 | 338.14 | 961.24 |
| S04879 | Ex1 2-234 | 2 | 234 | 2 | 2 | 1 | 16.86 | 5.66 | 1.68 | 97.18 | 24.35 | 1.83 | 59.61 | 42.52 | 320.55 | 1171.81 |
| S04901 | Ex1 2-314 | 2 | 314 | 3 | 2 | 1 | 17.67 | 6.17 | 1.25 | 80.00 | 39.55 | 15.71 | 60.55 | 28.45 | 349.04 | 1067.71 |
| S04898 | Ex1 2-131 | 2 | 131 | 1 | 2 | 2 | 11.60 | 18.10 | 2.30 | 65.18 | 47.59 | 17.89 | 46.60 | 39.41 | 259.71 | 863.33 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S04884 | Ex1 2-233 | 2 | 233 | 2 | 2 | 2 | 15.80 | 4.70 | 1.91 | 119.13 | 40.04 | 19.54 | 51.77 | 49.96 | 199.91 | 1772.75 |
| S04877 | Ex1 2-312 | 2 | 312 | 3 | 2 | 2 | 11.58 | 14.67 | 1.11 | 77.19 | 42.48 | 16.22 | 49.13 | 40.35 | 342.25 | 835.29 |
| S04895 | Ex1 2-132 | 2 | 132 | 1 | 2 | 3 | 9.81 | 12.55 | 1.64 | 79.99 | 37.80 | 15.44 | 53.49 | 38.27 | 286.91 | 1202.52 |
| S04887 | Ex1 2-232 | 2 | 232 | 2 | 2 | 3 | 12.46 | 5.10 | 2.76 | 99.14 | 36.44 | 18.88 | 32.32 | 77.68 | 255.45 | 1611.41 |
| S04886 | Ex1 2-311 | 2 | 311 | 3 | 2 | 3 | 7.26 | 7.52 | 1.16 | 68.44 | 27.92 | 13.14 | 50.30 | 28.21 | 341.05 | 820.56 |
| S04896 | Ex1 2-133 | 2 | 133 | 1 | 2 | 4 | 10.19 | 15.38 | 1.32 | 99.14 | 55.75 | 30.18 | 38.88 | 37.51 | 286.67 | 908.61 |
| S04882 | Ex1 2-231 | 2 | 231 | 2 | 2 | 4 | 9.12 | 4.70 | 2.67 | 65.33 | 27.30 | 13.47 | 49.19 | 81.98 | 327.24 | 1291.49 |
| S04874 | Ex1 2-313 | 2 | 313 | 3 | 2 | 4 | 13.64 | 11.23 | 1.59 | 76.56 | 41.80 | 16.93 | 47.91 | 35.70 | 366.79 | 944.98 |
| S04906 | Ex1 2-114 | 2 | 114 | 1 | 3 | 1 | 8.91 | 15.94 | 1.13 | 85.35 | 50.92 | 26.07 | 70.92 | 39.14 | 301.49 | 1015.65 |
| S04892 | Ex1 2-212 | 2 | 212 | 2 | 3 | 1 | 7.94 | 5.69 | 1.24 | 91.01 | 30.07 | 16.45 | 49.83 | 33.49 | 362.02 | 1323.00 |
| S04878 | Ex1 2-331 | 2 | 331 | 3 | 3 | 1 | 19.62 | 9.47 | 1.40 | 91.35 | 34.16 | 5.06 | 50.23 | 37.56 | 287.82 | 888.43 |
| S04904 | Ex1 2-112 | 2 | 112 | 1 | 3 | 2 | 14.42 | 13.95 | 1.28 | 130.04 | 60.56 | 32.20 | 70.78 | 39.06 | 300.88 | 1013.57 |
| S04883 | Ex1 2-213 | 2 | 213 | 2 | 3 | 2 | 9.49 | 6.25 | 19.22 | 102.79 | 30.95 | 15.21 | 53.56 | 31.23 | 362.00 | 1418.23 |
| S04894 | Ex1 2-333 | 2 | 333 | 3 | 3 | 2 | 11.49 | 15.19 | 1.40 | 87.07 | 33.09 | 6.40 | 127.31 | 57.93 | 362.56 | 778.61 |
| S04891 | Ex1 2-113 | 2 | 113 | 1 | 3 | 3 | 14.18 | 14.35 | 1.64 | 118.63 | 57.06 | 28.54 | 93.93 | 47.45 | 342.54 | 992.78 |
| S04902 | Ex1 2-214 | 2 | 214 | 2 | 3 | 3 | 18.21 | 12.50 | 1.24 | 105.81 | 53.67 | 22.96 | 47.12 | 39.87 | 404.13 | 1153.10 |
| S04876 | Ex1 2-334 | 2 | 334 | 3 | 3 | 3 | 10.20 | 16.99 | 1.32 | 116.19 | 55.39 | 28.19 | 42.66 | 42.49 | 325.72 | 896.61 |
| S04893 | Ex1 2-111 | 2 | 111 | 1 | 3 | 4 | 8.66 | 13.55 | 3.03 | 90.46 | 44.76 | 22.56 | 48.68 | 30.84 | 327.19 | 1084.10 |
| S04885 | Ex1 2-211 | 2 | 211 | 2 | 3 | 4 | 6.06 | 5.91 | 0.99 | 93.43 | 29.56 | 17.60 | 85.77 | 43.01 | 327.65 | 964.82 |
| S04873 | Ex1 2-332 | 2 | 332 | 3 | 3 | 4 | 11.16 | 7.66 | 1.36 | 121.84 | 39.40 | 20.57 | 46.17 | 44.70 | 468.56 | 984.68 |
| S04865 | Ex1 3-122 | 3 | 122 | 1 | 1 | 1 | 4.47 | 4.62 | 8.77 | 60.44 | 10.59 | 1.49 | 23.29 | 61.53 | 107.73 | 905.61 |
| S04867 | Ex1 3-221 | 3 | 221 | 2 | 1 | 1 | 3.64 | 5.39 | 3.85 | 59.05 | 25.84 | 16.80 | 18.76 | 20.92 | 54.02 | 317.42 |
| S04843 | Ex1 3-323 | 3 | 323 | 3 | 1 | 1 | 2.69 | 8.49 | 4.35 | 48.88 | 24.66 | 13.48 | 22.69 | 23.34 | 80.76 | 480.55 |
| S04851 | Ex1 3-124 | 3 | 124 | 1 | 1 | 2 | 3.09 | 5.14 | 4.38 | 47.25 | 8.59 | 0.36 | 23.70 | 16.80 | 50.09 | 319.89 |
| S04870 | Ex1 3-223 | 3 | 223 | 2 | 1 | 2 | 2.37 | 4.64 | 4.81 | 63.96 | 23.93 | 16.92 | 27.58 | 17.28 | 76.96 | 502.56 |
| S04862 | Ex1 3-322 | 3 | 322 | 3 | 1 | 2 | 3.13 | 5.00 | 5.17 | 55.84 | 8.73 | 0.61 | 78.02 | 31.73 | 64.43 | 440.06 |
| S04858 | Ex1 3-123 | 3 | 123 | 1 | 1 | 3 | 4.15 | 4.31 | 5.85 | 68.36 | 26.15 | 17.69 | 81.88 | 42.47 | 112.77 | 874.45 |
| S04872 | Ex1 3-222 | 3 | 222 | 2 | 1 | 3 | 3.63 | 8.79 | 4.22 | 62.02 | 31.44 | 19.02 | 37.85 | 24.83 | 105.00 | 538.06 |
| S04842 | Ex1 3-324 | 3 | 324 | 3 | 1 | 3 | 3.24 | 11.82 | 3.15 | 71.78 | 49.67 | 34.62 | 29.77 | 22.90 | 99.37 | 482.52 |
| S04857 | Ex1 3-121 | 3 | 121 | 1 | 1 | 4 | 4.64 | 11.07 | 9.03 | 54.50 | 27.60 | 11.89 | 23.49 | 42.79 | 127.05 | 1232.18 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S04859 | Ex1 3-224 | 3 | 224 | 2 | 1 | 4 | 2.95 | 4.64 | 3.58 | 67.76 | 7.58 | 0.00 | 27.28 | 20.66 | 71.92 | 528.07 |
| S04844 | Ex1 3-321 | 3 | 321 | 3 | 1 | 4 | 3.59 | 4.37 | 4.62 | 41.31 | 7.38 | 0.00 | 37.50 | 28.75 | 71.71 | 383.01 |
| S04860 | Ex1 3-134 | 3 | 134 | 1 | 2 | 1 | 4.20 | 6.71 | 6.20 | 41.96 | 26.76 | 15.84 | 52.49 | 29.46 | 59.90 | 364.12 |
| S04850 | Ex1 3-234 | 3 | 234 | 2 | 2 | 1 | 3.37 | 3.72 | 5.24 | 44.02 | 6.99 | 0.00 | 20.05 | 23.28 | 68.77 | 408.52 |
| S04837 | Ex1 3-314 | 3 | 314 | 3 | 2 | 1 | 3.70 | 6.32 | 5.66 | 54.74 | 26.50 | 16.47 | 78.43 | 31.98 | 55.17 | 448.06 |
| S04848 | Ex1 3-131 | 3 | 131 | 1 | 2 | 2 | 2.47 | 4.86 | 5.74 | 60.07 | 23.80 | 16.47 | 24.39 | 19.72 | 94.92 | 530.13 |
| S04852 | Ex1 3-233 | 3 | 233 | 2 | 2 | 2 | 2.51 | 4.69 | 4.21 | 60.15 | 24.41 | 17.22 | 29.27 | 18.19 | 56.91 | 326.22 |
| S04849 | Ex1 3-312 | 3 | 312 | 3 | 2 | 2 | 2.73 | 5.18 | 5.75 | 40.94 | 7.53 | 0.00 | 27.33 | 19.69 | 70.06 | 375.79 |
| S04847 | Ex1 3-132 | 3 | 132 | 1 | 2 | 3 | 2.85 | 5.72 | 5.33 | 44.46 | 23.77 | 15.20 | 29.61 | 20.42 | 77.87 | 427.56 |
| S04853 | Ex1 3-232 | 3 | 232 | 2 | 2 | 3 | 6.30 | 5.55 | 4.32 | 50.56 | 11.81 | 0.00 | 28.23 | 25.97 | 77.65 | 365.40 |
| S04845 | Ex1 3-311 | 3 | 311 | 3 | 2 | 3 | 2.46 | 5.85 | 4.97 | 54.30 | 25.71 | 17.40 | 33.99 | 28.25 | 116.36 | 463.77 |
| S04846 | Ex1 3-133 | 3 | 133 | 1 | 2 | 4 | 3.12 | 4.01 | 4.25 | 44.94 | 7.05 | 0.00 | 15.82 | 16.43 | 70.40 | 367.59 |
| S04854 | Ex1 3-231 | 3 | 231 | 2 | 2 | 4 | 3.24 | 4.88 | 4.22 | 51.49 | 24.15 | 16.04 | 26.92 | 21.07 | 83.24 | 530.98 |
| S04869 | Ex1 3-313 | 3 | 313 | 3 | 2 | 4 | 2.63 | 4.04 | 5.89 | 29.51 | 6.47 | 0.00 | 28.79 | 18.38 | 74.91 | 418.18 |
| S04861 | Ex1 3-114 | 3 | 114 | 1 | 3 | 1 | 4.35 | 5.53 | 11.63 | 48.38 | 11.84 | 1.96 | 47.67 | 36.24 | 128.33 | 1180.15 |
| S04856 | Ex1 3-212 | 3 | 212 | 2 | 3 | 1 | 3.85 | 4.37 | 3.00 | 41.68 | 7.78 | 0.00 | 25.65 | 19.39 | 107.60 | 407.60 |
| S04841 | Ex1 3-331 | 3 | 331 | 3 | 3 | 1 | 3.59 | 13.22 | 9.50 | 53.77 | 31.69 | 14.88 | 28.04 | 26.25 | 67.77 | 363.24 |
| S04864 | Ex1 3-112 | 3 | 112 | 1 | 3 | 2 | 3.15 | 4.68 | 4.32 | 41.75 | 23.58 | 15.75 | 26.38 | 19.44 | 71.22 | 410.10 |
| S04855 | Ex1 3-213 | 3 | 213 | 2 | 3 | 2 | 2.69 | 5.48 | 4.69 | 45.55 | 8.06 | 0.00 | 83.58 | 28.31 | 94.95 | 503.28 |
| S04838 | Ex1 3-333 | 3 | 333 | 3 | 3 | 2 | 2.43 | 9.60 | 6.31 | 66.63 | 48.23 | 36.20 | 22.28 | 18.75 | 89.39 | 419.96 |
| S04863 | Ex1 3-113 | 3 | 113 | 1 | 3 | 3 | 3.18 | 4.46 | 5.84 | 47.89 | 8.51 | 0.87 | 22.51 | 22.48 | 78.14 | 560.07 |
| S04866 | Ex1 3-214 | 3 | 214 | 2 | 3 | 3 | 2.75 | 6.45 | 3.55 | 44.88 | 9.59 | 0.39 | 25.60 | 16.71 | 87.26 | 505.65 |
| S04839 | Ex1 3-334 | 3 | 334 | 3 | 3 | 3 | 2.71 | 11.31 | 4.64 | 40.60 | 28.81 | 14.79 | 45.77 | 21.16 | 99.90 | 526.85 |
| S04868 | Ex1 3-111 | 3 | 111 | 1 | 3 | 4 | 2.56 | 4.63 | 4.66 | 40.61 | 8.21 | 1.03 | 26.02 | 17.69 | 79.42 | 423.84 |
| S04871 | Ex1 3-211 | 3 | 211 | 2 | 3 | 4 | 2.86 | 5.42 | 4.71 | 53.70 | 24.89 | 16.60 | 24.70 | 25.15 | 89.38 | 443.69 |
| S04840 | Ex1 3-332 | 3 | 332 | 3 | 3 | 4 | 3.07 | 10.48 | 4.52 | 54.30 | 35.03 | 21.49 | 32.80 | 25.91 | 71.43 | 358.25 |
| S04917 | Ex1 4-122 | 4 | 122 | 1 | 1 | 1 | 8.70 | 7.13 | 5.65 | 52.32 | 22.97 | 7.14 | 9.81 | 29.23 | 74.53 | 288.80 |
| S04943 | Ex1 4-221 | 4 | 221 | 2 | 1 | 1 | 16.05 | 4.95 | 1.01 | 34.38 | 23.39 | 2.39 | 94.07 | 58.31 | 55.81 | 213.47 |
| S04922 | Ex1 4-323 | 4 | 323 | 3 | 1 | 1 | 18.31 | 6.62 | 1.45 | 43.71 | 31.77 | 6.84 | 20.06 | 35.58 | 134.48 | 283.93 |
| S04930 | Ex1 4-124 | 4 | 124 | 1 | 1 | 2 | 10.12 | 6.41 | 2.20 | 45.85 | 14.74 | 0.00 | 13.47 | 25.16 | 70.34 | 303.02 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S04909 | Ex1 4-223 | 4 | 223 | 2 | 1 | 2 | 17.81 | 6.69 | 1.66 | 61.04 | 33.74 | 9.24 | 82.18 | 66.88 | 92.98 | 363.45 |
| S04935 | Ex1 4-322 | 4 | 322 | 3 | 1 | 2 | 25.68 | 8.28 | 1.11 | 48.29 | 41.30 | 7.33 | 19.43 | 27.65 | 73.92 | 240.05 |
| S04918 | Ex1 4-123 | 4 | 123 | 1 | 1 | 3 | 16.67 | 6.06 | 1.58 | 39.61 | 29.60 | 6.87 | 14.11 | 31.89 | 45.54 | 172.77 |
| S04914 | Ex1 4-222 | 4 | 222 | 2 | 1 | 3 | 28.55 | 8.21 | 1.26 | 42.00 | 33.58 | 0.00 | 11.36 | 42.93 | 77.75 | 300.89 |
| S04910 | Ex1 4-324 | 4 | 324 | 3 | 1 | 3 | 20.74 | 5.51 | 1.32 | 57.05 | 23.62 | 0.00 | 32.39 | 37.36 | 147.29 | 424.28 |
| S04934 | Ex1 4-121 | 4 | 121 | 1 | 1 | 4 | 34.90 | 7.23 | 1.00 | 38.16 | 36.20 | 0.00 | 27.85 | 52.72 | 133.14 | 329.23 |
| S04941 | Ex1 4-224 | 4 | 224 | 2 | 1 | 4 | 9.82 | 6.70 | 1.42 | 69.95 | 15.01 | 0.00 | 79.37 | 50.71 | 59.93 | 193.66 |
| S04937 | Ex1 4-321 | 4 | 321 | 3 | 1 | 4 | 17.97 | 6.23 | 3.79 | 48.75 | 31.20 | 7.00 | 73.95 | 72.17 | 73.05 | 269.03 |
| S04932 | Ex1 4-134 | 4 | 134 | 1 | 2 | 1 | 15.53 | 7.19 | 3.66 | 43.35 | 21.94 | 0.00 | 29.00 | 64.38 | 71.15 | 228.11 |
| S04912 | Ex1 4-234 | 4 | 234 | 2 | 2 | 1 | 16.37 | 4.78 | 1.28 | 36.10 | 17.49 | 0.00 | 16.52 | 47.35 | 80.17 | 294.44 |
| S04942 | Ex1 4-314 | 4 | 314 | 3 | 2 | 1 | 29.54 | 7.19 | 1.63 | 53.13 | 30.22 | 0.00 | 32.66 | 57.38 | 87.20 | 362.51 |
| S04940 | Ex1 4-131 | 4 | 131 | 1 | 2 | 2 | 7.42 | 7.10 | 1.05 | 35.35 | 21.11 | 6.59 | 20.97 | 27.39 | 55.54 | 221.77 |
| S04919 | Ex1 4-233 | 4 | 233 | 2 | 2 | 2 | 17.60 | 6.13 | 2.17 | 61.84 | 34.66 | 10.93 | 21.76 | 55.90 | 86.72 | 330.09 |
| S04938 | Ex1 4-312 | 4 | 312 | 3 | 2 | 2 | 15.20 | 9.24 | 1.37 | 35.82 | 25.32 | 0.88 | 28.65 | 55.56 | 62.88 | 258.40 |
| S04921 | Ex1 4-132 | 4 | 132 | 1 | 2 | 3 | 23.10 | 5.14 | 1.62 | 58.37 | 37.12 | 8.89 | 18.28 | 43.90 | 100.90 | 316.15 |
| S04926 | Ex1 4-232 | 4 | 232 | 2 | 2 | 3 | 8.84 | 4.60 | 1.47 | 39.93 | 22.78 | 9.34 | 19.01 | 39.11 | 52.32 | 197.47 |
| S04924 | Ex1 4-311 | 4 | 311 | 3 | 2 | 3 | 11.36 | 7.64 | 1.96 | 47.21 | 27.34 | 8.34 | 22.13 | 41.67 | 77.73 | 304.71 |
| S04933 | Ex1 4-133 | 4 | 133 | 1 | 2 | 4 | 9.97 | 6.59 | 1.34 | 60.16 | 26.91 | 10.35 | 21.79 | 46.38 | 163.31 | 396.61 |
| S04927 | Ex1 4-231 | 4 | 231 | 2 | 2 | 4 | 13.21 | 8.30 | 1.16 | 72.93 | 27.45 | 5.94 | 20.39 | 37.38 | 74.87 | 294.45 |
| S04936 | Ex1 4-313 | 4 | 313 | 3 | 2 | 4 | 19.69 | 6.05 | 1.24 | 55.85 | 35.07 | 9.33 | 20.13 | 52.79 | 69.90 | 287.80 |
| S04911 | Ex1 4-114 | 4 | 114 | 1 | 3 | 1 | 30.00 | 6.52 | 1.97 | 55.96 | 33.21 | 0.00 | 9.68 | 60.55 | 105.19 | 322.62 |
| S04928 | Ex1 4-212 | 4 | 212 | 2 | 3 | 1 | 11.41 | 5.28 | 2.08 | 47.57 | 24.84 | 8.15 | 14.73 | 35.46 | 70.03 | 266.14 |
| S04915 | Ex1 4-331 | 4 | 331 | 3 | 3 | 1 | 9.40 | 5.64 | 1.21 | 34.52 | 19.75 | 4.70 | 27.44 | 48.48 | 54.17 | 214.26 |
| S04925 | Ex1 4-112 | 4 | 112 | 1 | 3 | 2 | 11.77 | 6.07 | 2.27 | 38.31 | 22.04 | 4.20 | 20.25 | 42.74 | 71.89 | 300.22 |
| S04913 | Ex1 4-213 | 4 | 213 | 2 | 3 | 2 | 14.93 | 6.10 | 1.43 | 58.23 | 19.31 | 0.00 | 73.39 | 49.93 | 101.15 | 413.17 |
| S04916 | Ex1 4-333 | 4 | 333 | 3 | 3 | 2 | 12.80 | 10.20 | 1.95 | 40.67 | 26.74 | 3.74 | 21.42 | 33.12 | 81.62 | 356.23 |
| S04920 | Ex1 4-113 | 4 | 113 | 1 | 3 | 3 | 14.71 | 6.59 | 1.85 | 36.62 | 24.96 | 3.66 | 20.13 | 28.44 | 52.13 | 186.46 |
| S04931 | Ex1 4-214 | 4 | 214 | 2 | 3 | 3 | 20.89 | 7.05 | 1.65 | 49.07 | 37.11 | 9.17 | 35.25 | 56.12 | 77.79 | 299.76 |
| S04944 | Ex1 4-334 | 4 | 334 | 3 | 3 | 3 | 16.79 | 12.41 | 3.00 | 111.55 | 36.53 | 7.33 | 19.48 | 59.12 | 107.54 | 313.13 |
| S04923 | Ex1 4-111 | 4 | 111 | 1 | 3 | 4 | 18.24 | 5.93 | 1.70 | 63.00 | 34.70 | 10.53 | 22.27 | 34.85 | 67.91 | 238.13 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S04929 | Ex1 4-211 | 4 | 211 | 2 | 3 | 4 | 9.72 | 5.91 | 6.18 | 40.76 | 23.77 | 8.13 | 14.17 | 36.52 | 43.33 | 147.62 |
| S04939 | Ex1 4-332 | 4 | 332 | 3 | 3 | 4 | 22.21 | 5.57 | 1.89 | 61.28 | 37.06 | 9.27 | 60.76 | 66.89 | 70.79 | 295.09 |

## APPENDIX II

## EXPERIMENT 2 : SOIL AMENDMENTS

| | | | | | | | Nutrient Mass | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | $NO_3$-N | $NH_4$-N | $PO_4$-P | EOC | TEN | EON | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
| TAMU ID | Sample Name | Zone | Plot | Rep | P | N | mg/kg | | | | | | | | | |
| S05021 | ExII 1-136 | 136 | 1 | 1 | 1 | 1 | 5.57 | 7.98 | 32.64 | 43.10 | 12.17 | 0.00 | 16.81 | 133.88 | 97.81 | 619.90 |
| S05001 | ExII 1-232 | 232 | 1 | 2 | 1 | 1 | 11.73 | 9.39 | 38.28 | 57.08 | 21.54 | 0.42 | 22.24 | 57.90 | 52.21 | 346.44 |
| S05390 | ExII 1-316 | 316 | 1 | 3 | 1 | 1 | 7.68 | 7.33 | 12.62 | 38.80 | 12.37 | 0.00 | 93.64 | 85.37 | 53.07 | 387.88 |
| S05022 | ExII 1-135 | 135 | 1 | 1 | 1 | 2 | 8.92 | 8.64 | 33.44 | 43.61 | 13.14 | 0.00 | 41.20 | 104.21 | 105.89 | 652.77 |
| S05032 | ExII 1-233 | 233 | 1 | 2 | 1 | 2 | 7.27 | 7.21 | 15.63 | 55.39 | 12.07 | 0.00 | 17.13 | 72.36 | 66.93 | 499.82 |
| S04984 | ExII 1-312 | 312 | 1 | 3 | 1 | 2 | 10.88 | 7.92 | 40.64 | 42.05 | 15.50 | 0.00 | 39.64 | 113.78 | 82.58 | 513.25 |
| S05033 | ExII 1-133 | 133 | 1 | 1 | 1 | 3 | 12.01 | 7.31 | 25.98 | 54.77 | 15.28 | 0.00 | 42.57 | 80.34 | 97.17 | 659.38 |
| S05016 | ExII 1-231 | 231 | 1 | 2 | 1 | 3 | 10.55 | 5.88 | 37.26 | 48.46 | 14.43 | 0.00 | 36.79 | 82.77 | 70.20 | 550.01 |
| S05014 | ExII 1-313 | 313 | 1 | 3 | 1 | 3 | 9.76 | 7.96 | 13.51 | 35.26 | 16.13 | 0.00 | 36.41 | 62.15 | 54.09 | 351.39 |
| S05028 | ExII 1-131 | 131 | 1 | 1 | 1 | 4 | 8.86 | 7.56 | 60.73 | 54.16 | 14.11 | 0.00 | 44.87 | 97.00 | 93.27 | 659.73 |
| S05015 | ExII 1-235 | 235 | 1 | 2 | 1 | 4 | 8.74 | 8.20 | 27.84 | 45.71 | 15.81 | 0.00 | 26.45 | 110.02 | 81.25 | 612.66 |
| S04985 | ExII 1-311 | 311 | 1 | 3 | 1 | 4 | 9.15 | 7.32 | 14.51 | 39.25 | 14.64 | 0.00 | 33.29 | 87.44 | 59.33 | 478.41 |
| S05030 | ExII 1-134 | 134 | 1 | 1 | 1 | 5 | 11.10 | 8.24 | 41.79 | 60.72 | 18.70 | 0.00 | 43.22 | 123.58 | 147.07 | 850.97 |
| S05003 | ExII 1-236 | 236 | 1 | 2 | 1 | 5 | 11.33 | 7.95 | 45.07 | 51.60 | 15.98 | 0.00 | 24.09 | 86.35 | 49.70 | 315.02 |
| S04983 | ExII 1-315 | 315 | 1 | 3 | 1 | 5 | 11.61 | 7.87 | 33.11 | 61.93 | 18.29 | 0.00 | 43.26 | 96.75 | 73.32 | 439.49 |
| S05031 | ExII 1-132 | 132 | 1 | 1 | 1 | 6 | 45.36 | 21.26 | 320.06 | 216.31 | 65.53 | 0.00 | 69.71 | 539.14 | 388.35 | 2169.14 |
| S05034 | ExII 1-314 | 314 | 1 | 1 | 1 | 6 | 14.09 | 7.91 | 42.18 | 60.76 | 23.33 | 1.33 | 43.99 | 151.01 | 85.36 | 485.91 |
| S05013 | ExII 1-234 | 234 | 1 | 2 | 1 | 6 | 16.53 | 7.70 | 43.32 | 71.81 | 22.48 | 0.00 | 39.06 | 117.44 | 80.30 | 516.68 |
| S05026 | ExII 1-116 | 116 | 1 | 1 | 2 | 1 | 17.11 | 10.31 | 39.82 | 55.94 | 25.02 | 0.00 | 39.49 | 92.57 | 93.96 | 579.70 |
| S05002 | ExII 1-225 | 225 | 1 | 2 | 2 | 1 | 7.50 | 8.03 | 55.22 | 48.63 | 13.09 | 0.00 | 15.82 | 105.49 | 78.96 | 514.51 |
| S05012 | ExII 1-332 | 332 | 1 | 3 | 2 | 1 | 10.42 | 8.95 | 38.30 | 57.96 | 16.83 | 0.00 | 31.22 | 114.41 | 80.89 | 509.36 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05000 | ExII 1-113 | 113 | 1 | 1 | 2 | 2 | 11.75 | 8.30 | 43.28 | 65.92 | 19.39 | 0.00 | 24.50 | 108.26 | 82.05 | 579.64 |
| S05017 | ExII 1-222 | 222 | 1 | 2 | 2 | 2 | 16.44 | 6.51 | 45.03 | 56.47 | 19.96 | 0.00 | 27.98 | 106.77 | 72.88 | 559.23 |
| S05008 | ExII 1-336 | 336 | 1 | 3 | 2 | 2 | 28.04 | 9.34 | 22.34 | 57.66 | 34.50 | 0.00 | 40.23 | 70.55 | 43.77 | 353.30 |
| S04997 | ExII 1-114 | 114 | 1 | 1 | 2 | 3 | 8.41 | 7.47 | 38.69 | 43.90 | 13.39 | 0.00 | 34.57 | 71.90 | 52.00 | 393.87 |
| S05007 | ExII 1-223 | 223 | 1 | 2 | 2 | 3 | 12.10 | 6.63 | 66.58 | 55.44 | 15.99 | 0.00 | 33.00 | 120.64 | 64.94 | 464.51 |
| S05004 | ExII 1-331 | 331 | 1 | 3 | 2 | 3 | 11.34 | 6.57 | 17.53 | 66.13 | 16.53 | 0.00 | 83.83 | 104.15 | 78.44 | 589.85 |
| S04995 | ExII 1-115 | 115 | 1 | 1 | 2 | 4 | 7.15 | 6.57 | 30.20 | 97.93 | 17.97 | 4.24 | 121.64 | 98.65 | 76.32 | 548.40 |
| S04982 | ExII 1-224 | 224 | 1 | 2 | 2 | 4 | 12.86 | 4.06 | 43.89 | 45.14 | 13.15 | 0.00 | 40.94 | 94.49 | 81.56 | 575.67 |
| S04986 | ExII 1-334 | 334 | 1 | 3 | 2 | 4 | 6.74 | 7.87 | 24.11 | 44.25 | 12.48 | 0.00 | 40.98 | 89.21 | 50.72 | 316.96 |
| S05018 | ExII 1-112 | 112 | 1 | 1 | 2 | 5 | 10.22 | 9.54 | 74.79 | 52.22 | 20.40 | 0.64 | 82.65 | 140.57 | 92.70 | 697.05 |
| S05024 | ExII 1-221 | 221 | 1 | 2 | 2 | 5 | 8.41 | 9.42 | 38.92 | 69.94 | 18.58 | 0.75 | 19.75 | 101.60 | 61.76 | 472.42 |
| S04981 | ExII 1-335 | 335 | 1 | 3 | 2 | 5 | 7.85 | 8.38 | 27.41 | 35.81 | 12.06 | 0.00 | 39.54 | 132.34 | 61.84 | 349.66 |
| S04999 | ExII 1-111 | 111 | 1 | 1 | 2 | 6 | 12.11 | 6.30 | 92.74 | 60.58 | 15.47 | 0.00 | 92.66 | 159.09 | 104.02 | 824.47 |
| S04994 | ExII 1-226 | 226 | 1 | 2 | 2 | 6 | 14.46 | 7.33 | 78.17 | 61.35 | 20.06 | 0.00 | 41.90 | 141.59 | 96.10 | 549.94 |
| S04990 | ExII 1-333 | 333 | 1 | 3 | 2 | 6 | 18.11 | 7.39 | 45.05 | 71.86 | 24.05 | 0.00 | 39.77 | 131.07 | 102.59 | 495.37 |
| S05010 | ExII 1-121 | 121 | 1 | 1 | 3 | 1 | 8.16 | 8.69 | 155.12 | 52.64 | 17.68 | 0.84 | 39.96 | 100.64 | 73.30 | 581.40 |
| S05027 | ExII 1-211 | 211 | 1 | 2 | 3 | 1 | 9.75 | 6.71 | 87.67 | 48.94 | 13.98 | 0.00 | 22.28 | 106.76 | 75.99 | 585.15 |
| S04996 | ExII 1-324 | 324 | 1 | 3 | 3 | 1 | 10.75 | 8.94 | 11.40 | 28.76 | 13.26 | 0.00 | 42.13 | 71.61 | 43.29 | 339.51 |
| S05009 | ExII 1-122 | 122 | 1 | 1 | 3 | 2 | 9.64 | 7.13 | 115.89 | 54.52 | 14.65 | 0.00 | 25.32 | 99.30 | 86.38 | 572.07 |
| S05011 | ExII 1-214 | 214 | 1 | 2 | 3 | 2 | 18.28 | 5.46 | 70.73 | 46.53 | 20.32 | 0.00 | 37.94 | 116.83 | 99.65 | 663.59 |
| S04998 | ExII 1-321 | 321 | 1 | 3 | 3 | 2 | 15.00 | 5.90 | 11.80 | 46.21 | 15.43 | 0.00 | 12.46 | 86.39 | 84.91 | 583.99 |
| S04993 | ExII 1-124 | 124 | 1 | 1 | 3 | 3 | 14.16 | 7.44 | 42.28 | 51.68 | 18.61 | 0.00 | 37.93 | 107.32 | 89.86 | 601.07 |
| S05029 | ExII 1-213 | 213 | 1 | 2 | 3 | 3 | 22.55 | 6.17 | 43.75 | 58.98 | 25.43 | 0.00 | 49.02 | 151.54 | 115.95 | 705.25 |
| S04991 | ExII 1-325 | 325 | 1 | 3 | 3 | 3 | 10.78 | 7.49 | 27.79 | 56.93 | 16.18 | 0.00 | 75.42 | 102.03 | 70.77 | 452.08 |
| S04988 | ExII 1-126 | 126 | 1 | 1 | 3 | 4 | 10.87 | 6.92 | 135.00 | 68.36 | 14.94 | 0.00 | 29.77 | 115.42 | 99.70 | 765.79 |
| S04992 | ExII 1-215 | 215 | 1 | 2 | 3 | 4 | 9.47 | 8.22 | 44.62 | 94.72 | 23.34 | 5.65 | 41.84 | 119.04 | 106.70 | 608.45 |
| S05023 | ExII 1-323 | 323 | 1 | 3 | 3 | 4 | 12.65 | 7.29 | 18.76 | 45.01 | 18.08 | 0.00 | 45.97 | 67.16 | 68.86 | 383.41 |
| S05391 | EXII 1-123 | 123 | 1 | 1 | 3 | 5 | 10.69 | 5.98 | 23.01 | 64.31 | 15.23 | 0.00 | 38.02 | 110.82 | 106.88 | 715.78 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05020 | ExII 1-212 | 212 | 1 | 2 | 3 | 5 | 14.78 | 9.92 | 333.55 | 57.77 | 20.43 | 0.00 | 42.49 | 161.72 | 102.97 | 704.30 |
| S05019 | ExII 1-322 | 322 | 1 | 3 | 3 | 5 | 9.65 | 6.90 | 26.28 | 45.33 | 14.25 | 0.00 | 88.63 | 97.34 | 75.30 | 439.62 |
| S04987 | ExII 1-125 | 125 | 1 | 1 | 3 | 6 | 13.69 | 7.24 | 84.56 | 59.77 | 19.62 | 0.00 | 83.46 | 151.49 | 104.90 | 656.89 |
| S05025 | ExII 1-216 | 216 | 1 | 2 | 3 | 6 | 16.12 | 7.87 | 96.12 | 72.66 | 21.76 | 0.00 | 13.19 | 129.77 | 124.69 | 679.10 |
| S04989 | ExII 1-326 | 326 | 1 | 3 | 3 | 6 | 13.32 | 6.81 | 37.51 | 49.96 | 17.18 | 0.00 | 41.57 | 111.90 | 87.29 | 487.17 |
| S05141 | ExII 2-136 | 136 | 2 | 1 | 1 | 1 | 6.89 | 4.45 | 15.88 | 99.02 | 12.88 | 1.53 | 33.34 | 58.19 | 363.95 | 1124.15 |
| S05114 | ExII 2-232 | 232 | 2 | 2 | 1 | 1 | 14.36 | 4.73 | 2.73 | 87.59 | 18.67 | 0.00 | 52.17 | 53.32 | 329.41 | 1306.98 |
| S05094 | ExII 2-316 | 316 | 2 | 3 | 1 | 1 | 5.99 | 5.16 | 5.35 | 80.65 | 14.77 | 3.62 | 53.49 | 34.42 | 346.43 | 1509.35 |
| S05140 | ExII 2-135 | 135 | 2 | 1 | 1 | 2 | 6.96 | 5.70 | 1.87 | 75.39 | 14.09 | 1.44 | 41.04 | 44.09 | 376.93 | 1258.40 |
| S05108 | ExII 2-233 | 233 | 2 | 2 | 1 | 2 | 13.07 | 6.13 | 3.65 | 75.65 | 18.50 | 0.00 | 95.77 | 61.07 | 351.12 | 1154.48 |
| S05104 | ExII 2-312 | 312 | 2 | 3 | 1 | 2 | 6.19 | 5.28 | 2.55 | 91.39 | 11.22 | 0.00 | 44.80 | 34.44 | 278.46 | 936.72 |
| S05135 | ExII 2-133 | 133 | 2 | 1 | 1 | 3 | 7.54 | 5.49 | 2.93 | 68.02 | 11.73 | 0.00 | 49.22 | 48.48 | 315.17 | 1173.93 |
| S05097 | ExII 2-231 | 231 | 2 | 2 | 1 | 3 | 9.26 | 4.53 | 2.61 | 79.75 | 16.97 | 3.19 | 30.23 | 45.01 | 312.24 | 1325.50 |
| S05095 | ExII 2-313 | 313 | 2 | 3 | 1 | 3 | 14.85 | 5.66 | 4.86 | 113.54 | 27.04 | 6.53 | 51.25 | 58.09 | 291.32 | 1051.64 |
| S05112 | ExII 2-131 | 131 | 2 | 1 | 1 | 4 | 8.26 | 4.89 | 2.55 | 85.22 | 13.16 | 0.01 | 41.84 | 55.33 | 338.00 | 1012.29 |
| S05102 | ExII 2-311 | 311 | 2 | 3 | 1 | 4 | 10.94 | 5.87 | 2.83 | 148.04 | 29.83 | 13.02 | 52.17 | 43.38 | 366.67 | 1297.99 |
| S05127 | ExII 2-134 | 134 | 2 | 1 | 1 | 5 | 8.82 | 4.61 | 4.15 | 121.65 | 20.76 | 7.32 | 91.39 | 75.86 | 367.59 | 1398.34 |
| S05105 | ExII 2-236 | 236 | 2 | 2 | 1 | 5 | 8.97 | 6.94 | 2.92 | 87.59 | 16.37 | 0.46 | 52.48 | 43.31 | 329.91 | 1023.73 |
| S05096 | ExII 2-315 | 315 | 2 | 3 | 1 | 5 | 10.39 | 4.60 | 3.36 | 96.02 | 17.20 | 2.20 | 54.28 | 70.79 | 322.11 | 1092.61 |
| S05138 | ExII 2-132 | 132 | 2 | 1 | 1 | 6 | 10.62 | 3.48 | 7.71 | 92.58 | 15.76 | 1.66 | 99.47 | 57.11 | 298.40 | 1318.04 |
| S05124 | ExII 2-234 | 234 | 2 | 2 | 1 | 6 | 11.22 | 4.65 | 9.13 | 123.92 | 19.95 | 4.08 | 70.96 | 106.40 | 341.95 | 1008.33 |
| S05098 | ExII 2-314 | 314 | 2 | 3 | 1 | 6 | 10.32 | 4.29 | 15.64 | 89.75 | 20.50 | 5.88 | 59.42 | 73.67 | 358.64 | 1124.95 |
| S05134 | ExII 2-116 | 116 | 2 | 1 | 2 | 1 | 9.01 | 4.89 | 22.19 | 140.86 | 18.90 | 5.00 | 45.68 | 30.76 | 274.79 | 1519.70 |
| S05111 | ExII 2-225 | 225 | 2 | 2 | 2 | 1 | 13.62 | 9.66 | 11.57 | 122.20 | 30.33 | 7.05 | 45.22 | 52.63 | 352.63 | 1201.06 |
| S05090 | ExII 2-332 | 332 | 2 | 3 | 2 | 1 | 8.04 | 5.19 | 4.56 | 75.15 | 13.53 | 0.30 | 36.26 | 41.54 | 318.18 | 958.04 |
| S05132 | ExII 2-113 | 113 | 2 | 1 | 2 | 2 | 9.82 | 5.17 | 2.65 | 113.49 | 20.30 | 5.30 | 35.68 | 35.82 | 390.34 | 1314.37 |
| S05139 | ExII 2-222 | 222 | 2 | 2 | 2 | 2 | 13.21 | 10.89 | 3.53 | 105.59 | 32.64 | 8.54 | 93.33 | 51.54 | 332.32 | 1387.20 |
| S05092 | ExII 2-336 | 336 | 2 | 3 | 2 | 2 | 9.61 | 8.64 | 5.28 | 94.31 | 20.52 | 2.27 | 46.65 | 35.92 | 341.73 | 954.44 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05133 | ExII 2-114 | 114 | 2 | 1 | 2 | 3 | 8.05 | 5.80 | 8.12 | 110.08 | 15.48 | 1.63 | 27.94 | 29.78 | 314.80 | 1351.86 |
| S05119 | ExII 2-223 | 223 | 2 | 2 | 2 | 3 | 9.44 | 7.39 | 3.07 | 68.34 | 16.16 | 0.00 | 42.22 | 45.94 | 267.83 | 1123.45 |
| S05089 | ExII 2-331 | 331 | 2 | 3 | 2 | 3 | 9.14 | 5.77 | 4.62 | 105.61 | 17.59 | 2.68 | 43.71 | 65.70 | 320.65 | 1101.84 |
| S05137 | ExII 2-115 | 115 | 2 | 1 | 2 | 4 | 9.09 | 5.50 | 42.28 | 132.42 | 26.43 | 11.84 | 37.66 | 52.63 | 368.69 | 1411.76 |
| S05118 | ExII 2-224 | 224 | 2 | 2 | 2 | 4 | 9.06 | 4.22 | 127.71 | 110.10 | 19.91 | 6.63 | 44.57 | 86.87 | 292.55 | 1250.56 |
| S05091 | ExII 2-334 | 334 | 2 | 3 | 2 | 4 | 8.13 | 7.86 | 19.27 | 93.73 | 15.92 | 0.00 | 105.58 | 45.00 | 324.11 | 951.18 |
| S05129 | ExII 2-112 | 112 | 2 | 1 | 2 | 5 | 9.96 | 5.76 | 13.60 | 90.27 | 15.92 | 0.19 | 49.53 | 70.86 | 367.63 | 1014.81 |
| S05115 | ExII 2-221 | 221 | 2 | 2 | 2 | 5 | 16.91 | 7.12 | 81.97 | 123.50 | 29.56 | 5.54 | 55.61 | 81.54 | 330.27 | 1099.11 |
| S05093 | ExII 2-335 | 335 | 2 | 3 | 2 | 5 | 13.94 | 6.21 | 8.30 | 91.84 | 22.92 | 2.77 | 49.11 | 76.28 | 311.93 | 1099.43 |
| S05128 | ExII 2-111 | 111 | 2 | 1 | 2 | 6 | 12.18 | 6.39 | 71.88 | 121.74 | 21.31 | 2.74 | 33.95 | 126.96 | 346.38 | 1276.54 |
| S05117 | ExII 2-226 | 226 | 2 | 2 | 2 | 6 | 16.84 | 4.94 | 26.35 | 99.75 | 22.89 | 1.11 | 40.11 | 87.80 | 306.46 | 1426.20 |
| S05100 | ExII 2-333 | 333 | 2 | 3 | 2 | 6 | 10.10 | 4.70 | 26.40 | 75.06 | 14.65 | 0.00 | 47.99 | 48.58 | 346.31 | 958.56 |
| S05142 | ExII 2-121 | 121 | 2 | 1 | 3 | 1 | 9.35 | 4.21 | 3.88 | 118.66 | 20.17 | 6.61 | 89.62 | 38.66 | 326.01 | 1539.56 |
| S05121 | ExII 2-211 | 211 | 2 | 2 | 3 | 1 | 19.30 | 4.73 | 24.94 | 260.22 | 41.70 | 17.67 | 49.77 | 85.85 | 295.67 | 1856.79 |
| S05106 | ExII 2-324 | 324 | 2 | 3 | 3 | 1 | 6.36 | 5.29 | 5.39 | 42.14 | 9.26 | 0.00 | 32.88 | 33.33 | 265.98 | 837.33 |
| S05136 | ExII 2-122 | 122 | 2 | 1 | 3 | 2 | 21.09 | 11.31 | 4.19 | 72.26 | 28.37 | 0.00 | 45.29 | 38.91 | 355.75 | 1203.07 |
| S05107 | ExII 2-321 | 321 | 2 | 3 | 3 | 2 | 12.89 | 5.87 | 7.81 | 186.19 | 30.50 | 11.74 | 29.33 | 39.12 | 307.01 | 1661.07 |
| S05130 | ExII 2-124 | 124 | 2 | 1 | 3 | 3 | 8.04 | 3.93 | 6.25 | 70.16 | 10.98 | 0.00 | 48.55 | 23.64 | 220.75 | 1284.04 |
| S05120 | ExII 2-213 | 213 | 2 | 2 | 3 | 3 | 9.66 | 3.76 | 6.33 | 66.26 | 14.47 | 1.05 | 202.43 | 80.51 | 180.86 | 726.39 |
| S05099 | ExII 2-325 | 325 | 2 | 3 | 3 | 3 | 10.06 | 6.32 | 6.30 | 102.67 | 21.38 | 5.01 | 31.76 | 42.03 | 358.28 | 1176.02 |
| S05126 | ExII 2-126 | 126 | 2 | 1 | 3 | 4 | 6.66 | 4.57 | 3.68 | 55.45 | 9.04 | 0.00 | 66.61 | 31.34 | 291.99 | 1066.28 |
| S05113 | ExII 2-215 | 215 | 2 | 2 | 3 | 4 | 11.96 | 11.51 | 5.01 | 95.73 | 24.65 | 1.18 | 63.29 | 44.85 | 287.16 | 1026.58 |
| S05101 | ExII 2-323 | 323 | 2 | 3 | 3 | 4 | 6.10 | 5.28 | 13.13 | 99.14 | 16.28 | 4.89 | 47.77 | 42.47 | 334.27 | 1224.25 |
| S05131 | ExII 2-123 | 123 | 2 | 1 | 3 | 5 | 8.75 | 3.69 | 120.44 | 122.41 | 17.57 | 5.12 | 43.97 | 57.48 | 310.85 | 1458.98 |
| S05123 | ExII 2-212 | 212 | 2 | 2 | 3 | 5 | 16.72 | 4.33 | 39.29 | 199.61 | 36.05 | 15.00 | 44.50 | 107.56 | 285.03 | 2456.93 |
| S05122 | ExII 2-322 | 322 | 2 | 3 | 3 | 5 | 11.66 | 4.92 | 26.59 | 128.44 | 23.76 | 7.18 | 28.97 | 69.12 | 331.65 | 1474.24 |
| S05125 | ExII 2-125 | 125 | 2 | 1 | 3 | 6 | 11.11 | 4.13 | 28.06 | 99.10 | 16.87 | 1.63 | 41.91 | 84.32 | 379.81 | 1267.79 |
| S05110 | ExII 2-216 | 216 | 2 | 2 | 3 | 6 | 15.63 | 4.81 | 30.77 | 134.69 | 28.39 | 7.95 | 78.05 | 120.47 | 326.22 | 1260.37 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05103 | ExII 2-326 | 326 | 2 | 3 | 3 | 6 | 14.99 | 4.78 | 11.37 | 122.55 | 27.37 | 7.61 | 51.32 | 66.46 | 118.20 | 503.22 |
| S05176 | ExII 3-136 | 136 | 3 | 1 | 1 | 1 | 0.93 | 6.58 | 8.57 | 48.80 | 8.39 | 0.89 | 29.50 | 33.79 | 64.66 | 314.20 |
| S05153 | ExII 3-232 | 232 | 3 | 2 | 1 | 1 | 1.26 | 5.24 | 13.07 | 54.58 | 8.66 | 2.16 | 52.77 | 32.89 | 70.50 | 450.31 |
| S05189 | ExII 3-316 | 316 | 3 | 3 | 1 | 1 | 4.66 | 5.26 | 10.96 | 62.85 | 18.52 | 8.60 | 22.32 | 55.21 | 91.37 | 579.35 |
| S05187 | ExII 3-135 | 135 | 3 | 1 | 1 | 2 | 6.03 | 5.67 | 8.24 | 63.82 | 18.90 | 7.20 | 59.40 | 32.69 | 77.23 | 448.16 |
| S05158 | ExII 3-233 | 233 | 3 | 2 | 1 | 2 | 1.56 | 7.73 | 7.82 | 43.44 | 10.91 | 1.62 | 27.65 | 26.75 | 72.47 | 381.88 |
| S05159 | ExII 3-312 | 312 | 3 | 3 | 1 | 2 | 1.97 | 5.10 | 10.65 | 47.32 | 7.88 | 0.81 | 19.99 | 44.79 | 69.05 | 360.89 |
| S05180 | ExII 3-133 | 133 | 3 | 1 | 1 | 3 | 3.31 | 6.08 | 10.51 | 52.66 | 10.99 | 1.60 | 32.65 | 40.64 | 83.58 | 548.73 |
| S05150 | ExII 3-231 | 231 | 3 | 2 | 1 | 3 | 6.10 | 5.87 | 6.63 | 50.44 | 14.10 | 2.13 | 61.19 | 41.48 | 83.38 | 445.73 |
| S05161 | ExII 3-313 | 313 | 3 | 3 | 1 | 3 | 7.78 | 5.55 | 8.19 | 50.79 | 14.06 | 0.73 | 48.05 | 64.96 | 121.25 | 518.66 |
| S05169 | ExII 3-131 | 131 | 3 | 1 | 1 | 4 | 5.62 | 10.44 | 4.69 | 73.45 | 34.98 | 18.92 | 31.76 | 37.76 | 110.50 | 630.77 |
| S05152 | ExII 3-311 | 311 | 3 | 3 | 1 | 4 | 3.27 | 4.75 | 14.02 | 56.89 | 14.56 | 6.53 | 34.02 | 51.90 | 90.34 | 437.44 |
| S05156 | ExII 3-235 | 235 | 3 | 3 | 1 | 4 | 4.04 | 10.98 | 20.81 | 66.71 | 38.56 | 23.54 | 38.50 | 30.70 | 94.31 | 519.05 |
| S05196 | ExII 3-134 | 134 | 3 | 1 | 1 | 5 | 1.97 | 6.29 | 21.56 | 52.30 | 9.32 | 1.06 | 23.64 | 82.50 | 100.88 | 578.62 |
| S05188 | ExII 3-236 | 236 | 3 | 2 | 1 | 5 | 6.16 | 5.75 | 45.14 | 71.91 | 19.87 | 7.95 | 89.16 | 109.12 | 102.76 | 685.86 |
| S05160 | ExII 3-315 | 315 | 3 | 3 | 1 | 5 | 1.46 | 5.07 | 11.08 | 47.09 | 7.05 | 0.51 | 33.20 | 60.06 | 73.51 | 412.20 |
| S05184 | ExII 3-132 | 132 | 3 | 1 | 1 | 6 | 7.28 | 5.96 | 14.08 | 56.60 | 17.11 | 3.86 | 27.06 | 92.27 | 111.04 | 675.20 |
| S05175 | ExII 3-234 | 234 | 3 | 2 | 1 | 6 | 4.78 | 5.35 | 30.23 | 60.05 | 10.89 | 0.76 | 31.71 | 92.04 | 111.24 | 515.43 |
| S05173 | ExII 3-314 | 314 | 3 | 3 | 1 | 6 | 2.11 | 4.61 | 17.56 | 58.36 | 7.90 | 1.18 | 26.88 | 108.86 | 100.50 | 384.39 |
| S05185 | ExII 3-116 | 116 | 3 | 1 | 2 | 1 | 2.32 | 6.01 | 13.66 | 50.52 | 11.06 | 2.73 | 26.48 | 40.87 | 80.60 | 438.85 |
| S05181 | ExII 3-225 | 225 | 3 | 2 | 2 | 1 | 1.05 | 5.54 | 41.53 | 58.22 | 7.25 | 0.65 | 30.96 | 39.87 | 81.66 | 681.24 |
| S05144 | ExII 3-332 | 332 | 3 | 3 | 2 | 1 | 4.04 | 4.66 | 16.10 | 62.27 | 12.21 | 3.51 | 26.26 | 57.16 | 122.11 | 876.58 |
| S05191 | ExII 3-113 | 113 | 3 | 1 | 2 | 2 | 3.47 | 12.56 | 18.61 | 49.81 | 12.81 | 0.00 | 24.10 | 55.35 | 122.84 | 528.84 |
| S05166 | ExII 3-222 | 222 | 3 | 2 | 2 | 2 | 5.52 | 9.18 | 7.63 | 69.14 | 22.25 | 7.55 | 25.08 | 40.58 | 86.57 | 588.44 |
| S05145 | ExII 3-336 | 336 | 3 | 3 | 2 | 2 | 3.96 | 5.35 | 20.15 | 64.45 | 17.50 | 8.19 | 40.16 | 46.29 | 54.02 | 365.78 |
| S05186 | ExII 3-114 | 114 | 3 | 1 | 2 | 3 | 4.27 | 13.25 | 19.15 | 69.73 | 30.14 | 12.62 | 57.00 | 45.16 | 83.10 | 408.83 |
| S05165 | ExII 3-223 | 223 | 3 | 2 | 2 | 3 | 4.48 | 6.63 | 8.06 | 66.37 | 20.41 | 9.30 | 41.30 | 39.50 | 87.56 | 601.68 |
| S05146 | ExII 3-331 | 331 | 3 | 3 | 2 | 3 | 6.10 | 6.19 | 22.81 | 79.97 | 20.97 | 8.69 | 29.53 | 75.15 | 121.56 | 1103.48 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05195 | ExII 3-115 | 115 | 3 | 1 | 2 | 4 | 2.10 | 17.74 | 16.17 | 81.73 | 35.56 | 15.72 | 34.28 | 62.24 | 103.80 | 531.67 |
| S05177 | ExII 3-224 | 224 | 3 | 2 | 2 | 4 | 6.87 | 5.76 | 12.41 | 62.02 | 16.80 | 4.17 | 25.75 | 39.76 | 80.81 | 552.10 |
| S05193 | ExII 3-334 | 334 | 3 | 3 | 2 | 4 | 3.47 | 5.30 | 11.78 | 57.81 | 15.83 | 7.06 | 42.44 | 37.70 | 59.75 | 399.94 |
| S05172 | ExII 3-112 | 112 | 3 | 1 | 2 | 5 | 5.37 | 9.63 | 43.06 | 77.13 | 40.02 | 25.01 | 23.26 | 71.95 | 107.21 | 586.57 |
| S05179 | ExII 3-221 | 221 | 3 | 2 | 2 | 5 | 4.22 | 5.51 | 28.95 | 66.78 | 10.94 | 1.21 | 50.39 | 114.08 | 125.66 | 678.18 |
| S05151 | ExII 3-335 | 335 | 3 | 3 | 2 | 5 | 3.82 | 4.59 | 25.18 | 66.63 | 15.83 | 7.41 | 29.29 | 68.81 | 67.46 | 432.26 |
| S05174 | ExII 3-111 | 111 | 3 | 1 | 2 | 6 | 6.68 | 14.39 | 42.95 | 96.19 | 47.17 | 26.10 | 25.89 | 116.04 | 114.99 | 1048.58 |
| S05170 | ExII 3-226 | 226 | 3 | 2 | 2 | 6 | 5.90 | 16.14 | 99.44 | 66.54 | 33.70 | 11.66 | 30.04 | 72.03 | 86.28 | 653.64 |
| S05143 | ExII 3-333 | 333 | 3 | 3 | 2 | 6 | 4.81 | 4.86 | 36.96 | 84.76 | 17.86 | 8.18 | 34.44 | 123.76 | 119.33 | 770.79 |
| S05194 | ExII 3-121 | 121 | 3 | 1 | 3 | 1 | 4.05 | 4.48 | 62.31 | 68.60 | 15.65 | 7.13 | 32.66 | 34.02 | 79.99 | 733.20 |
| S05163 | ExII 3-211 | 211 | 3 | 2 | 3 | 1 | 0.65 | 6.47 | 66.22 | 44.14 | 9.81 | 2.69 | 22.24 | 35.42 | 50.01 | 336.97 |
| S05157 | ExII 3-324 | 324 | 3 | 3 | 3 | 1 | 4.84 | 4.33 | 204.59 | 84.72 | 16.78 | 7.61 | 44.22 | 69.59 | 105.90 | 1039.00 |
| S05178 | ExII 3-122 | 122 | 3 | 1 | 3 | 2 | 2.91 | 6.92 | 45.39 | 57.17 | 12.29 | 2.47 | 43.80 | 29.96 | 71.84 | 457.29 |
| S05182 | ExII 3-214 | 214 | 3 | 2 | 3 | 2 | 6.25 | 5.02 | 16.92 | 63.32 | 13.65 | 2.38 | 38.44 | 47.16 | 123.51 | 754.41 |
| S05149 | ExII 3-321 | 321 | 3 | 3 | 3 | 2 | 5.54 | 5.64 | 10.30 | 74.21 | 19.77 | 8.59 | 41.82 | 44.25 | 105.90 | 785.31 |
| S05167 | ExII 3-124 | 124 | 3 | 1 | 3 | 3 | 3.81 | 16.80 | 17.30 | 59.21 | 33.68 | 13.06 | 30.27 | 36.36 | 57.32 | 382.32 |
| S05183 | ExII 3-213 | 213 | 3 | 2 | 3 | 3 | 2.62 | 7.36 | 18.33 | 48.23 | 11.68 | 1.70 | 21.51 | 29.87 | 62.54 | 402.50 |
| S05147 | ExII 3-325 | 325 | 3 | 3 | 3 | 3 | 5.08 | 5.39 | 87.98 | 72.36 | 18.24 | 7.77 | 25.60 | 52.23 | 85.88 | 691.62 |
| S05171 | ExII 3-126 | 126 | 3 | 1 | 3 | 4 | 4.54 | 15.18 | 42.04 | 75.23 | 41.02 | 21.30 | 30.21 | 43.76 | 93.51 | 546.26 |
| S05162 | ExII 3-215 | 215 | 3 | 2 | 3 | 4 | 2.93 | 5.51 | 14.32 | 54.13 | 8.51 | 0.07 | 30.74 | 45.73 | 120.44 | 738.37 |
| S05155 | ExII 3-323 | 323 | 3 | 3 | 3 | 4 | 3.76 | 4.61 | 67.97 | 70.32 | 12.37 | 3.99 | 23.71 | 65.41 | 110.36 | 954.26 |
| S05190 | ExII 3-123 | 123 | 3 | 1 | 3 | 5 | 2.95 | 21.67 | 36.77 | 67.72 | 36.79 | 12.17 | 34.91 | 72.03 | 82.38 | 465.05 |
| S05192 | ExII 3-212 | 212 | 3 | 2 | 3 | 5 | 2.22 | 7.39 | 14.37 | 64.68 | 20.09 | 10.49 | 20.91 | 58.51 | 63.60 | 367.15 |
| S05148 | ExII 3-322 | 322 | 3 | 3 | 3 | 5 | 4.82 | 4.54 | 16.97 | 60.14 | 12.62 | 3.27 | 31.02 | 110.66 | 118.89 | 894.38 |
| S05168 | ExII 3-125 | 125 | 3 | 1 | 3 | 6 | 1.76 | 16.39 | 34.09 | 68.46 | 33.19 | 15.04 | 53.23 | 84.75 | 79.40 | 430.29 |
| S05164 | ExII 3-216 | 216 | 3 | 2 | 3 | 6 | 4.04 | 5.70 | 37.83 | 72.07 | 11.43 | 1.69 | 24.69 | 127.41 | 127.23 | 753.57 |
| S05154 | ExII 3-326 | 326 | 3 | 3 | 3 | 6 | 7.13 | 4.88 | 89.59 | 103.71 | 21.68 | 9.67 | 90.91 | 168.57 | 163.15 | 1211.81 |
| S05072 | ExII 4-136 | 136 | 4 | 1 | 1 | 1 | 8.55 | 41.98 | 7.46 | 54.73 | 57.48 | 6.96 | 49.29 | 39.45 | 44.09 | 166.47 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05068 | ExII 4-232 | 232 | 4 | 2 | 1 | 1 | 5.69 | 5.22 | 4.25 | 73.62 | 8.73 | 0.00 | 35.82 | 41.49 | 69.86 | 256.73 |
| S05042 | ExII 4-316 | 316 | 4 | 3 | 1 | 1 | 9.82 | 3.96 | 10.69 | 52.46 | 9.80 | 0.00 | 28.21 | 51.83 | 57.31 | 217.29 |
| S05082 | ExII 4-135 | 135 | 4 | 1 | 1 | 2 | 7.04 | 18.00 | 2.41 | 48.43 | 23.76 | 0.00 | 65.80 | 35.14 | 45.77 | 169.19 |
| S05062 | ExII 4-233 | 233 | 4 | 2 | 1 | 2 | 7.96 | 4.56 | 2.27 | 52.02 | 10.20 | 0.00 | 89.89 | 66.32 | 88.09 | 358.39 |
| S05045 | ExII 4-312 | 312 | 4 | 3 | 1 | 2 | 27.24 | 8.54 | 4.29 | 40.65 | 32.36 | 0.00 | 24.83 | 32.76 | 51.18 | 199.88 |
| S05087 | ExII 4-133 | 133 | 4 | 1 | 1 | 3 | 22.33 | 21.42 | 4.12 | 68.05 | 36.74 | 0.00 | 164.98 | 46.66 | 43.25 | 185.32 |
| S05061 | ExII 4-231 | 231 | 4 | 2 | 1 | 3 | 13.26 | 8.83 | 4.34 | 84.58 | 20.79 | 0.00 | 49.09 | 39.98 | 67.70 | 224.63 |
| S05049 | ExII 4-313 | 313 | 4 | 3 | 1 | 3 | 33.14 | 11.47 | 7.58 | 46.43 | 40.97 | 0.00 | 84.95 | 41.04 | 45.77 | 204.38 |
| S05069 | ExII 4-131 | 131 | 4 | 1 | 1 | 4 | 7.86 | 15.33 | 3.67 | 36.91 | 23.97 | 0.78 | 46.92 | 35.42 | 65.91 | 243.71 |
| S05043 | ExII 4-235 | 235 | 4 | 2 | 1 | 4 | 11.43 | 3.68 | 4.24 | 39.37 | 21.44 | 6.33 | 81.09 | 58.56 | 55.24 | 230.46 |
| S05044 | ExII 4-311 | 311 | 4 | 3 | 1 | 4 | 11.44 | 4.14 | 9.49 | 42.63 | 12.66 | 0.00 | 28.09 | 30.63 | 58.24 | 215.39 |
| S05083 | ExII 4-134 | 134 | 4 | 1 | 1 | 5 | 9.58 | 25.38 | 6.16 | 51.30 | 33.20 | 0.00 | 47.70 | 54.49 | 47.85 | 214.79 |
| S05041 | ExII 4-236 | 236 | 4 | 2 | 1 | 5 | 13.74 | 3.52 | 5.28 | 32.59 | 18.55 | 1.29 | 18.82 | 41.58 | 70.96 | 277.71 |
| S05035 | ExII 4-315 | 315 | 4 | 3 | 1 | 5 | 14.00 | 3.51 | 4.59 | 45.79 | 14.53 | 0.00 | 84.68 | 44.15 | 55.51 | 212.15 |
| S05086 | ExII 4-132 | 132 | 4 | 1 | 1 | 6 | 14.92 | 33.66 | 9.30 | 118.02 | 50.17 | 1.59 | 44.17 | 76.68 | 86.67 | 370.11 |
| S05037 | ExII 4-234 | 234 | 4 | 2 | 1 | 6 | 13.42 | 5.78 | 14.24 | 57.70 | 17.42 | 0.00 | 32.49 | 82.07 | 78.32 | 300.89 |
| S05036 | ExII 4-314 | 314 | 4 | 3 | 1 | 6 | 21.08 | 5.78 | 23.04 | 54.81 | 22.53 | 0.00 | 37.51 | 77.05 | 81.14 | 395.66 |
| S05075 | ExII 4-116 | 116 | 4 | 1 | 2 | 1 | 9.95 | 7.17 | 16.57 | 48.09 | 14.13 | 0.00 | 47.87 | 48.43 | 68.68 | 224.26 |
| S05066 | ExII 4-225 | 225 | 4 | 2 | 2 | 1 | 6.66 | 8.84 | 30.37 | 64.10 | 13.52 | 0.00 | 46.45 | 36.95 | 57.25 | 226.62 |
| S05051 | ExII 4-332 | 332 | 4 | 3 | 2 | 1 | 14.10 | 4.42 | 6.48 | 41.73 | 16.05 | 0.00 | 39.96 | 27.81 | 54.20 | 223.81 |
| S05077 | ExII 4-113 | 113 | 4 | 1 | 2 | 2 | 15.35 | 25.59 | 5.03 | 72.61 | 49.78 | 8.83 | 32.05 | 35.42 | 48.22 | 203.82 |
| S05067 | ExII 4-222 | 222 | 4 | 2 | 2 | 2 | 14.02 | 9.80 | 10.68 | 72.74 | 21.05 | 0.00 | 36.30 | 32.51 | 52.02 | 209.15 |
| S05047 | ExII 4-336 | 336 | 4 | 3 | 2 | 2 | 17.76 | 3.42 | 6.72 | 55.47 | 27.74 | 6.56 | 26.75 | 28.15 | 84.56 | 282.68 |
| S05078 | ExII 4-114 | 114 | 4 | 1 | 2 | 3 | 10.74 | 10.40 | 5.68 | 67.35 | 29.06 | 7.92 | 47.15 | 43.38 | 66.85 | 239.32 |
| S05060 | ExII 4-223 | 223 | 4 | 2 | 2 | 3 | 14.27 | 8.03 | 4.38 | 76.03 | 19.26 | 0.00 | 65.86 | 34.13 | 57.05 | 248.97 |
| S05038 | ExII 4-331 | 331 | 4 | 3 | 2 | 3 | 11.10 | 4.85 | 4.94 | 52.15 | 22.10 | 6.16 | 32.38 | 36.69 | 53.87 | 208.27 |
| S05073 | ExII 4-115 | 115 | 4 | 1 | 2 | 4 | 7.47 | 7.91 | 4.68 | 35.68 | 18.49 | 3.10 | 54.67 | 43.51 | 66.87 | 213.66 |
| S05058 | ExII 4-224 | 224 | 4 | 2 | 2 | 4 | 10.88 | 13.15 | 6.39 | 62.97 | 21.99 | 0.00 | 34.73 | 32.79 | 64.23 | 245.04 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S05046 | ExII 4-334 | 334 | 4 | 3 | 2 | 4 | 10.69 | 3.82 | 3.30 | 35.92 | 11.07 | 0.00 | 16.93 | 25.70 | 44.04 | 195.19 |
| S05070 | ExII 4-112 | 112 | 4 | 1 | 2 | 5 | 7.98 | 20.94 | 55.84 | 87.31 | 31.68 | 2.75 | 48.06 | 53.25 | 61.62 | 269.32 |
| S05057 | ExII 4-221 | 221 | 4 | 2 | 2 | 5 | 6.45 | 8.50 | 6.92 | 64.48 | 13.59 | 0.00 | 90.68 | 71.63 | 77.29 | 285.09 |
| S05052 | ExII 4-335 | 335 | 4 | 3 | 2 | 5 | 12.45 | 4.13 | 7.34 | 36.81 | 12.75 | 0.00 | 35.53 | 36.82 | 39.78 | 139.12 |
| S05085 | ExII 4-111 | 111 | 4 | 1 | 2 | 6 | 11.71 | 8.11 | 7.23 | 65.12 | 16.99 | 0.00 | 35.87 | 44.21 | 63.10 | 236.01 |
| S05059 | ExII 4-226 | 226 | 4 | 2 | 2 | 6 | 12.56 | 10.27 | 26.25 | 49.60 | 18.74 | 0.00 | 67.63 | 107.13 | 90.94 | 340.36 |
| S05050 | ExII 4-333 | 333 | 4 | 3 | 2 | 6 | 15.03 | 4.38 | 8.23 | 54.30 | 15.10 | 0.00 | 73.87 | 62.48 | 46.86 | 190.82 |
| S05084 | ExII 4-121 | 121 | 4 | 1 | 3 | 1 | 12.47 | 4.64 | 2.67 | 58.38 | 15.07 | 0.00 | 55.41 | 33.34 | 69.82 | 248.21 |
| S05056 | ExII 4-211 | 211 | 4 | 2 | 3 | 1 | 9.23 | 20.27 | 330.13 | 76.50 | 30.01 | 0.52 | 113.98 | 51.98 | 70.43 | 899.04 |
| S05088 | ExII 4-324 | 324 | 4 | 3 | 3 | 1 | 8.81 | 5.47 | 5.89 | 46.80 | 20.31 | 6.03 | 23.55 | 30.52 | 49.97 | 221.59 |
| S05076 | ExII 4-122 | 122 | 4 | 1 | 3 | 2 | 13.88 | 6.82 | 4.10 | 57.87 | 18.23 | 0.00 | 40.73 | 37.87 | 53.66 | 227.91 |
| S05071 | ExII 4-214 | 214 | 4 | 2 | 3 | 2 | 9.45 | 17.91 | 7.17 | 63.87 | 25.98 | 0.00 | 51.80 | 32.23 | 51.95 | 224.78 |
| S05048 | ExII 4-321 | 321 | 4 | 3 | 3 | 2 | 8.69 | 3.71 | 3.04 | 30.14 | 7.86 | 0.00 | 37.34 | 29.31 | 55.46 | 236.10 |
| S05074 | ExII 4-124 | 124 | 4 | 1 | 3 | 3 | 12.54 | 28.95 | 4.46 | 81.51 | 44.45 | 2.95 | 55.58 | 33.61 | 46.46 | 223.08 |
| S05064 | ExII 4-213 | 213 | 4 | 2 | 3 | 3 | 27.62 | 25.38 | 5.60 | 106.82 | 53.91 | 0.91 | 51.81 | 32.48 | 55.64 | 277.07 |
| S05054 | ExII 4-325 | 325 | 4 | 3 | 3 | 3 | 12.82 | 3.66 | 3.17 | 41.53 | 12.78 | 0.00 | 23.38 | 22.37 | 63.10 | 244.32 |
| S05080 | ExII 4-126 | 126 | 4 | 1 | 3 | 4 | 12.17 | 19.36 | 2.47 | 47.86 | 28.76 | 0.00 | 41.73 | 35.20 | 55.26 | 236.94 |
| S05063 | ExII 4-215 | 215 | 4 | 2 | 3 | 4 | 11.08 | 27.23 | 15.23 | 63.94 | 37.45 | 0.00 | 43.26 | 48.74 | 67.87 | 247.73 |
| S05040 | ExII 4-323 | 323 | 4 | 3 | 3 | 4 | 9.24 | 6.46 | 12.34 | 81.62 | 13.54 | 0.00 | 31.18 | 28.98 | 48.76 | 202.95 |
| S05081 | ExII 4-123 | 123 | 4 | 1 | 3 | 5 | 8.30 | 11.39 | 4.24 | 69.18 | 17.68 | 0.00 | 43.63 | 44.30 | 53.82 | 248.95 |
| S05055 | ExII 4-212 | 212 | 4 | 2 | 3 | 5 | 14.99 | 21.32 | 18.15 | 73.32 | 35.31 | 0.00 | 39.03 | 72.86 | 65.97 | 607.94 |
| S05039 | ExII 4-322 | 322 | 4 | 3 | 3 | 5 | 13.16 | 3.86 | 12.51 | 46.40 | 23.50 | 6.48 | 23.95 | 40.57 | 73.36 | 295.83 |
| S05079 | ExII 4-125 | 125 | 4 | 1 | 3 | 6 | 10.52 | 30.76 | 12.24 | 45.92 | 36.09 | 0.00 | 41.29 | 57.53 | 59.18 | 289.20 |
| S05065 | ExII 4-216 | 216 | 4 | 2 | 3 | 6 | 6.89 | 4.58 | 23.18 | 73.16 | 16.97 | 5.50 | 42.14 | 88.18 | 98.90 | 363.63 |
| S05053 | ExII 4-326 | 326 | 4 | 3 | 3 | 6 | 12.47 | 3.38 | 7.43 | 35.71 | 11.94 | 0.00 | 38.06 | 50.81 | 51.77 | 209.84 |